# THE CHANGES IN THE DISTRIBUTION OF PASTURE AND WEED SPECIES IN A GRAZED TROPICAL PASTURE

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ABSTRACT

This pasture ecological study was conducted at Hawaii Agricultural Experiment Station, Kauai Branch, from July 1978 to October 1978. The pasture area covered two steep-sided slopes facing north and south. A valley which runs east and west separates the two slopes. No fertilizer was added to the pasture since 1970 and the area was continuously grazed since 1973. The objective was to find the changes in species distribution and soil factors comparing results of the same area studied in 1971 (Nicholls, 1972). Data were collected using the belt transect method.

Of the dominant pasture species of 1971, intortum [Desmodium intortum (Mill.) Urb.] had disappeared from the pasture, green panicgrass [Panicum maximum Jacq. (var. trichoglume Eyles)] was only found on middle sections of both slopes in areas where it was protected from grazing. Stylo [Stylosanthes guianensis (Aubl.)] and pangolagrass [Digitaria decumbens Stent.] had spread to lower parts of the slope.

In 1978, the pasture was dominated by weeds. The species present in greater frequency at all locations in the pasture were Hawaiian elephantfoot [Elephantopus mollis H. B. K.], Boston fern [Nephrolepis exaltata (L.) Schott.], glenwood grass [Sacciolepis indica (Wight & Arn.) Hitchc.] and sour paspalum [Paspalum conjugatum Bergius]. Hawaiian elephantfoot had spread to the valley bottom. Indicator weed species of pasture deterioration such as lantana [Lantana camara L.], melastoma [Melastoma malabatricum L.], nettleleaf vervain [Stachytarpheta urticaefolia (Salisb.) Sims] had increased in numbers, while American

burnweed [Erechtites hieracifolia (L.) Raf.] decreased in number. Other weed species present in 1978 were knotroot foxtail [Setaria geniculata (Lam.) Beauv.] and ricegrass paspalum [Paspalum orbiculare Forst.] dominating the middle and top sections of the slope, and guava [Psidium guajava L.] dominating the valley bottom.

Soil factors were also measured. Soil extractable P decreased while exchangeable K, Mg and Ca increased since 1971.

The deteriorating pasture of 1978 produced very low dry matter production for cattle feed.

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# INTRODUCTION

In the tropics, the infestation of pasture and range land by noxious weeds, shrubs, trees and various poisonous plants poses one of the most difficult and troublesome problems with which livestock managers have to deal. Such infestation may completely destroy the grazing value of the land. Their eradication may cost more than the land is worth. This is especially true in many areas of the tropics where pastures are grown on marginal lands. It is therefore necessary for the managers to be able to identify the problem early so that a control program can be initiated at an early date. Every manager needs to know when to allow his pasture to be grazed to the degree that will still insure good production in the years to follow. In addition, for a productive pasture, good maintenance of soil fertility is a must and accurate judging of pasture conditions is necessary. He must be able to determine from present evidence whether the pasture is improving, or whether it is deteriorating. As far as possible, actual facts must be used as the basis for judgement.

This ecological study was therefore conducted to identify changes in vegetation and soil factors (moisture, pH, extractable phosphorus, exchangeable calcium, potassium and magnesium) of a deteriorating tropical pasture. The study was done on a grazed pasture area at Kauai Branch Station from July 1978 to October 1978. The same pasture area was thoroughly investigated by Nicholls (1972). In 1971, the pasture was productive and dominated by improved pasture species of stylo, intortum and green panicgrass. The weed species were made up of sour paspalum, knotroot foxtail and spreading dayflower. Since 1973, the area had been continuously grazed. In 1978, the pasture area was dominated by weeds.

Samplings of vegetation and soils were made in order to identify vegetation pattern, trends and changes that had occurred in the pasture since the last sampling by Nicholls (1972). Vegetation samplings were done in July and October to coincide with dry and wet periods, respectively.

Therefore, the objectives of this study were as follows:

1. To find the distribution patterns of the dominant species in 1978,
2. To find the changes in distribution patterns of dominant and indicator species of 1971, using Nicholls (1972) results for comparison,
3. To find the changes in weed and pasture species occurrence between the wet and the dry periods, particularly those species that were sensitive to rainfall,
4. To estimate the dry matter yield of the pasture and its botanical composition,
5. To define the soil factors (moisture content, pH, extractable phosphorus, exchangeable calcium, potassium and magnesium), and the changes since 1971.

# LITERATURE REVIEW

## ECOLOGICAL STUDY OF VEGETATION DISTRIBUTION

### Methods of Study

There are two basic methods of studying plant communities. The first one is the structural method, which is basically diagrammatic and does not require the identification of species. The second is the floristic or species composition method. This latter method requires the identification of the species present in the community. Thus, a detailed botanical composition of an area can be made. Since it is time consuming, it is restricted to the study of small areas.

The structural concept of vegetation was first used by Gam (1918). He categorized a plant community into different growth forms and functions which he called 'synusia'. Lippma (1939) considered 'synusiae' as layer communities, such as moss, herb, shrub and tree layers. A detailed structural method of study was presented by Dansereau (1947, 1951). He recorded plant communities based on six categories, namely plant life form, size, coverage, function, leaf shape and size, and leaf texture. Each of these categories was further broken down into different criteria. Kuchler (1967) used different subdivisions. He divided vegetation into two broad categories: woody vegetation and herbaceous vegetation. Woody and herbaceous vegetation were divided into ten physiognomic categories, which were further differentiated into life forms, leaf characteristics, height (stratifications) and coverage. Another structural method was that of Fosberg (1961) who classified vegetation as closed, open or sparse. This method strictly records existing vegetation and avoids incorporation of environmental criteria.

Although the structural method is not very useful for studying grassland and range lands, it is widely used in the study of forest vegetation. It has also been used to show relations of vegetation to topography (Hough and Forbes, 1943; Beard, 1944; and Egler, 1948).

With the floristic method, an investigator must be able to identify the plant species in the community. This can be time consuming. This method is useful in the study of species associations, trends in distribution along slopes and to monitor changes and succession in vegetation over a period of time. Various workers used this method to study succession and vegetation composition in range lands (Anderson and Talbot, 1965; Anderson and Herlocker, 1973; Ares and Leon, 1972). Moomaw and Takahashi (1960) used the floristic method in the study of vegetation of Wailua Game Reserve in Kauai. They recorded the vegetation in terms of frequency of occurrence and also as percentage ground cover. Ares and Leon (1972), in the study of ecological succession in range land of Argentina, used this method which was appropriate in identifying the species indicators of succession.

Whether one chooses the structural or the floristic method, the basic sampling unit used has been the line transect. In a study area, reference lines are set up uniformly, from which measurements on vegetation are made. The first worker to use line transect was Bauer (1936, 1943) in the studies on the composition of vegetation of Chaparral. Warren-Wilson and Leigh (1964) and West and Ibrahim (1968) used line transect in their studies of vegetation. Another method was the line intercept (Edwards, 1950). Other workers (Anderson, 1952; and Parker and Savage, 1944) used the line intercept method, but measurements were made within a narrow area along the transect (belt transect). Turner (1971) used the belt transect method in the study of salt desert shrub of Western Colorado. Nicholls (1972), in an ecological study of pasture area in Kauai, used the modified belt transect method. This method was made up by 'rolling' a quadrat along the transect lines and vegetation data were collected along these lines.

## Factors Affecting Plant Distribution

Geographical distribution of plants is mainly due to climate. But in an area where the climate is the same, plant distribution is influenced by topography, soil, altitude and by the activities of man and animals. Also, plant biomass production is affected by these factors (Hallsworth, 1969). Warren-Wilson and Leigh (1964) and Torsell (1973) have shown that even a small variation in topography can produce a large effect on vegetation.

Slope is one of the factors which influences the properties of soil and the duration of sunlight, and therefore slope affects plant growth and distribution (Shreve, 1924; Norton and Smith, 1930; Auten, 1945; Aandahl, 1948; Perring, 1959; Warren-Wilson and Leigh, 1964; Singh and Misra, 1969; and Smith, 1977). Smith (1977) showed the marked differences in vegetation of east- and west-facing slopes of Mount Wilhelm in New Guinea. Because of clear mornings and cloudy afternoons, the east-facing slope had more species due to more sunshine and higher temperatures. Auten (1945) indicated that the distribution patterns of forest species depended on aspect, exposure and position on slope. He suggested that upper slope was usually of coarser textured soil and shallower than that of lower slope. Thus upper slope was drier because its soil had greater drainage and evaporation rates, lower water storage capacity, was less sheltered from the winds, and part of its water was lost through seepage. Norton and Smith (1930) also reported a variation in soil profile characteristics with the steepness of the slopes. As the steepness increased, the depth of the profile decreased, and the texture changed from a heavy clay to silt loam. Singh and Misra (1969) showed the influence of slope position on growth characteristics of goosegrass [Eleusine indica (L.) Gaertn.]. The south-facing slope received sunlight from midmorning and the north-facing slope was shaded from the sunlight after midmorning. As the result, growth of goosegrass was erect on north-facing slope and prostrate on south-facing slope. In the temperate zones, altitude and slope exposure affected soil temperature which might explain the vast vegetation differences on different slopes (Shreve, 1924).

Slope also affects soil fertility. Perring (1959) related various soil chemical factors to slope and exposure of chalk grassland area of England. Soil calcium was strongly correlated with slope aspect and it was higher on northern exposure. Soil pH and phosphorus content were governed by slope and not by aspect. Soil phosphorus was lower on steeper slopes but soil pH and potassium were higher on steeper slopes. Aandahl (1948) showed that variation in soil nitrogen was influenced by slope position, slope gradient, slope curvature and length of slope.

The importance of soil fertility in influencing vegetation distribution was shown by many workers (Levy, 1956; Loveday, 1964; Warren-Wilson and Leigh, 1964; Anderson and Talbot, 1965; and Anderson and Herlocker, 1973). Aside from light and water, soil fertility was the next most important factor in effecting changes in grassland association (Levy, 1956). In the study of vegetation distribution of plains of semi-arid region of Southern Australia, Warren-Wilson and Leight (1964) showed that percent vegetation cover increased with increases in depth of soil. In some areas where soil depressions occurred, soil water, soil calcium, potassium and magnesium increased progressively down the depression. The higher clay content in the depression accounted for the increase in nutrient content. Anderson and Herlocker (1973) showed that soil texture and water table determined the rooting pattern, percent foliage cover and height of grassland species. However, McCown *et al*. (1977) in studying the distribution patterns of Townsville stylo [*Stylosanthes humilis* H. B. K.] and some perennial grasses did not get any relationship between the species distribution patterns with soil phosphorus. However, the distribution of annual medics was correlated to soil phosphorus (Robinson, 1937; Bradshaw *et al*., 1960; Robson, 1969).

Soil moisture was highly correlated with rainfall (Hopkin, 1966). In contrast, Roger and King (1972) showed the relationship of soil moisture to the distribution of some grass species of *Agrostis-Festula* grassland.

Soil pH affects the distribution of some plant species. Roger and King (1972) showed that the distribution of *Agrostis-Festula* was related to pH. Nicholls (1972) reported the relationship of the distribution of bracken fern [Pteridium aquilinum (L.) Kuhn.] to soil pH. In contrast, Emmett and Ashby (1934) did not get any relationship between the distribution of bracken fern and pH, because of the high pH levels in which this species was tolerant. Also, soil pH is related to soil P and texture (Robson, 1969).

Another soil property that affects the distribution of plants is soil drainage. Its influence on the availability of minor elements to some species and on their growth and distribution were reported by many workers (Norton and Smith, 1930; Finn et al., 1961; Graven et al., 1965). Drainage patterns which were influenced by water content, soil depth and soil texture, affected species association (Pandeya, 1969).

The effects of activities of man (mainly by fire) and animals (grazing) on the survival and succession of species were demonstrated by several workers. The effect of fire on plant communities had been studied by Beadle (1940), Moomaw and Takahashi (1960) and Norman (1969). Moomaw and Takahashi (1960) showed that weedy plants of Kauai could be grouped into three types based on their response after burning. Certain species increased, others decreased and still others showed no response after burning. Ritson et al. (1971) had shown the influence of grazing pressure on the botanical composition of North Queensland pasture. With heavy grazing pressure, the perennial grasses declined but Townsville stylo increased. Naik and Misra (1974) showed that there was a progressive shift in dominant species of natural grassland of India, as the time of protection from grazing was increased. The shift was towards more perennial grass species. Deterioration in natural grassland in India was due to heavy cattle grazing (Kumar and Joshi, 1972).

Nicholls (1972) made a thorough ecological study of a pasture area in Kauai. His results are summarized below.

Of the environmental parameters measured along the transects, there was a marked increase in soil moisture, depth of soil profile, total nitrogen, exchangeable soil calcium, magnesium and manganese, soil pH (measured in 1N KCl and 1N $K_2SO_4$ solutions) and the daily maximum and afternoon temperatures at the ground surface, as one went down the slope. The parameters which decreased in value towards the valley bottom were soil pH (measured in water) and the morning temperature at the ground surface. Soil extractable phosphorus, exchangeable potassium and soil extractable silicon showed variabilities down the slope.

The pasture species stylo dominated the top of the slope and on the shallow soils of spurs and steep, eroded areas. Stylo distribution was therefore influenced by shallow soil profile and higher soil pH. Sour paspalum-knotroot foxtail association was also found on these areas and their distribution closely corresponded to the shallower soil profiles and lower soil moisture areas. The woody species dominating the ridgetop locations were lantana, melastoma, Hawaiian elephant-foot and nettleleaf vervain. Their distribution was related to water extractable silicon. Green panicgrass, intortum, spreading dayflower and American burnweed dominated the lower parts of the slope and the valley bottoms. Distribution of green panicgrass was related to soil moisture, total soil nitrogen and exchangeable manganese. Intortum was related to total soil nitrogen and soil calcium. Spreading dayflower distribution was influenced by lower soil pH, and American burnweed distribution corresponded to high total soil nitrogen and high soil moisture.

Effects of Nutrition on Improved Pasture Species

Soils of the tropics are generally of low fertility because of high rainfall and leaching and also due to P fixation by some tropical soils. Species of improved tropical pasture, on the other hand, have high fertility requirements for growth. Use of fertilizers is therefore necessary to raise soil fertility. Because of the high cost of fertilizers, the use of grass-legume pasture is the best alternative because the legume will provide nitrogen for the system.

Several workers have reviewed the characteristics of species of grasses and legumes used in the pasture mixtures (Williams, 1967; Davies and Hutton, 1970; Hutton, 1970; Williams and Andrew, 1970; Jones, 1972; and McIlroy, 1972). Reviews on specific species were on centro (Teitzel and Burt, 1976), guinea grass [*Panicum maximum* Jacq.] (Motta, 1953; McCosker and Teitzel, 1975), intortum (Bryan, 1966 and 1969; Rotar, 1969), pangolagrass (Nestel and Creek, 1962), stylo (Tuley, 1968) and *Stylosanthes* (Burt and Miller, 1975). These articles review species adaptation, agronomic characteristics and animal production.

In this literature review, emphasis will be made on stylo, intortum, pangolagrass, green panicgrass, and species of the same genus. These species were the dominant components of the pasture of the study area in 1971.

Nitrogen is one of the most important nutrients for growth. In a grass-legume pasture, the legume can contribute to a significant amount of nitrogen to the pasture system. In soils of low available nitrogen, the nodulated legume can supply most of its nitrogen requirement from fixation. This fixed nitrogen is made available to the pasture system through decay of plant materials and returns of animals' excreta. Henzell (1968) estimated annual nitrogen increments of 280 to 400 kg/ha under high quality, high yielding pasture; 170 to 280 kg/ha under good pasture; and 55 to 170 kg/ha under an average pasture which was strongly grazed. Annual amount of nitrogen fixed varies with species and conditions in which they are grown. For centro and intortum, the amount fixed was 240 and 340 kg/ha/year, respectively, of which only a small amount was transferred to the grass growing in association with it (Whitney et al., 1967).

The importance of phosphorus in plant nutrition is well recognized. The work of Andrew and Robins (1969a, 1969b, 1971) in Australia shows the species differences in internal critical levels of phosphorus. Legume species such as Townsville stylo and centro showed critical levels of 0.17% and 0.16%, respectively, which are lower than those of intortum (0.22%), glycine [Glycine wightii Willd.] (0.23%) and other temperate legumes (0.25%) (Andrew and Robins, 1969a). With stylo, Bruce (1974) found that the critical percentages were 0.16% for tips and 0.22% for plant tops. According to the results of Andrew and Robins (1969a), intortum was the most responsive and Townsville stylo was the least responsive to phosphorus applications. The amount of phosphorus accumulated in plant tops was highest for Townsville stylo at all levels of phosphorus applications. This ability to extract phosphorus efficiently from soils low in phosphorus is recognized by the fact that stylo and Townsville stylo are found on very poor soils where other legumes cannot survive (Roberts, 1970; Nicholls, 1972). Among the grasses, pangolagrass, guinea grass and molasses grass [Melinis minutiflora Beauv.] had lower critical levels than those of Rhodes grass [Chloris gayana Kunth], common paspalum [Paspalum dilatatum Poir.] and kikuyu grass [Pennisetum clandestinum Hochst.] (Andrew and Robins, 1971). Plucknett and Fox (1965) showed the importance of phosphorus fertilization for rapid establishment of pangolagrass and intortum in Hawaiian latosol.

Potassium is required in large amount by the grasses. Under optimum conditions, the amounts of potassium taken up by pangolagrass and guinea grass were slightly more than 400 kg/ha/year (Vicente-Chandler et al., 1974). Younge (1961) showed that in a pangolagrass-intortum-kaimi clover [Desmodium canum (Gmel.) Schinz and Thell.] pasture, a heavy dose of potassium resulted in pangolagrass becoming dominant. Brolmann and Sonoda (1975), using three cultivars of stylo, showed a decrease in plant phosphorus when the amounts of potassium applied were increased, and vice versa. To avoid yield reduction, they suggested a minimum value of 0.8% potassium in the stylo tops. However, with Townsville stylo, Andrew and Robins (1969c) reported potassium critical percentage of 0.6%. Centro and intortum had critical percentages of 0.75% and 0.80%, respectively. In another study on potassium interaction with other nutrient elements, Andrew and Robins (1969d) found that as potassium concentrations within the plant increased, the concentrations of other cations decreased.

Pangolagrass-intortum pasture adequately fertilized with lime, phosphorus and potassium yielded up to 22,400 kg/ha/year of dry matter (Younge et al., 1964).

Other nutrients such as calcium, magnesium, manganese, copper and aluminum have been studied by various workers (Andrew and Thorne, 1962; Andrew and Hegarty, 1969; Andrew et al., 1973; Andrew and Vanden Berg, 1973; and Spain, 1975). Stylo, Townsville stylo and centro were tolerant to high soil aluminum and manganese, and to low soil calcium and magnesium. Intortum also tolerated high soil aluminum and low soil calcium and magnesium, but it did not tolerate high soil manganese. Silverleaf desmodium [Desmodium uncinatum (Jacq.) DC.] and centro were least sensitive to low copper, but Stylosanthes bojeri Vog. was susceptible to low copper (Andrew and Thorne, 1962). The response of intortum to molybdenum was shown in Australia by Kerridge et al. (1973) and in Hawaii by Younge et al. (1964).

To summarize the results, stylo is tolerant to low soil phosphorus, calcium, magnesium and to high soil aluminum and manganese. Its tolerance to potassium and copper have not been reported, but Townsville stylo showed tolerance to low soil potassium (Andrew and Robins, 1969) and S. bojeri showed susceptibility to low copper (Andrew and Thorne, 1962). Intortum shows tolerance to low soil calcium and magnesium, and to high aluminum, but it is susceptible to low soil phosphorus, low potassium and to high manganese. Centro shows tolerance to low phosphorus, potassium, calcium, magnesium and to high aluminum and manganese. Pangolagrass and guinea grass are tolerant to low soil phosphorus. Both grasses require high amounts of potassium, and nitrogen (if it is not grown with legumes).

## Effects of Grazing on Improved Tropical Pastures

No serious deterioration occurs if the pasture is maintained at the right grazing pressure and high soil fertility. The short term effect of grazing is a decrease in dry matter yield of the pasture. If the pasture is allowed to rest, pasture species will recover and maintain good dry matter production. The long term effect is the change in botanical composition of the pasture and an increase in weed population, especially if grazing pressure is too heavy.

Under continuous grazing (set stocking), it was shown in a pasture of guinea grass-stylo-centro-peuro [*Peuroraria phaseoloides* (Roxb.) Benth.]-calopo [*Calopogonium mucunoides* Desv.] mixture, that the dry matter on offer of guinea grass and its legume components was significantly reduced at each increase in stocking rate (Eng *et al.*, 1978). The same trend was reported by Winter *et al.* (1977) in a pasture of signal grass [*Brachiaria decumbens* Stapf.], guinea grass, stylo and siratro [*Macroptilium atropurpureum* (DC.) Urb.]. Nicholls (1972) reported that pangolagrass dry matter yields before and after grazing remained almost the same. This was because of low utilization of pangolagrass by cattle. However, the percent dry weight contribution of green panicgrass decreased after each grazing.

Marked changes in botanical composition of pastures due to grazing pressure were shown by several workers. In a pasture of spear grass [*Heteropogon contortus* (L.) Beauv.] and Townsville stylo, heavy stocking rate decreased the population of the grass (Shaw and 't Mannetje, 1970). Also, increasing the grazing pressure resulted in an increase in Townsville stylo yields (Shaw and 't Mannetje, 1970; Ritson et al., 1970). The same trend was observed for siratro (Winter et al., 1977). With time, the legume content of the pasture decreased especially at high stocking rate (Bryan and Evans, 1973; Eng et al., 1978).

Weed population increases with an increase in stocking rates. This was shown by Gillard (1970), Bryan and Evans (1973) and Eng et al. (1978). Nicholls (1972) also found an increase in weed population after each grazing period.

## Nutrient Recycling

Under grazing conditions, P and K are returned to the soil through excreta, and the amount depended on the stocking rate of the pasture (Petersen et al., 1956). More than 80% of N, P and K consumed by cattle are excreted in their urine and feces (Mott, 1974). Thus, these nutrients are recycled back into the soil. Losses are due to removal of animals from the pasture, urea volatilization from feces and nutrient leaching. Hildes (1966) found an increase in soil K after two years of pasture grazing by sheep. The increase was especially marked on areas where sheep flocked together. Russell (1960) reported increases in soil N and organic matter after the pasture was grazed by sheep for a long period of time. Research literature on long term effects (more than five years) on soil fertility and species composition is limited. Bruce (1965) compared soil N, pH and soil organic carbon of guinea grass and guinea grass-centro pastures after fifteen years of grazing. Under guinea grass-centro pasture, soil N and organic carbon remained constant, whereas under guinea grass pasture, percent soil N and organic carbon decreased. Soil pH of guinea grass-centro pasture was significantly higher than that of guinea grass pasture. Aside from an increase in N to the soil due to legume fixation, a pasture of centro-African stargrass [Cynodon plectostachyus (K. Schum.) Pilg.] showed an increase in organic matter after two years of grazing (Moore, 1962).

In a degraded pasture where woody weeds have taken over most of the area, one would expect a recycling of nutrients by these deep-rooted woody species. Ebersohn and Lucas (1965) showed a positive correlation between growth of improved grasses under mature poplar box tree [Eucalyptus populnea R. Muell.] and higher P and K of soil of these locations. This was explained by the recycling of nutrients by the deep-rooted tree species, making the nutrients available to shallow-rooted grass species. The improved grasses responded more readily than the native species. Duane (1951),in an investigation of the profuse growth of clover under marri tree [Eucalyptus calophylla R. Br.] in Australia, suggested that an appreciable amount of mineral elements, especially K, were added to the soil by leaf fall.

Studies on forest vegetation have shown that leaching of nutrients from leaves occurs by rain (Tamm, 1951; Nye, 1961; Tamimi et al., 1974). In Ghana under semi-deciduous evergreen forest, Nye (1961) showed the amount of each element leached by rain from leaves of trees. The nutrients were $NH_4$-N, K, Ca, Mg and P, and the corresponding amounts leached annually were 3.4, 219.8, 29.2, 17.9, and 3.7 kg/ha. Tamimi et al. (1974) measured the pH and nutrient elements of rain water under different tree canopies in Hawaii. They found that the pH of water increased with increasing rainfall and the nutrients leached were $NH_4$-N, K, Ca, Mg, Si and P. The amounts leached annually were 12.0, 5.8, 4.6, 2.2, 1.6 and 0.2 kg/ha, respectively. The high amount of K and Ca leached by rain from the leaves was consistent even in a temperate forest (Tamm, 1951). The amounts of nutrients returned to the soils through leaf leaching and leaf fall were compared by Wills (1955). He found that under Pinus radiata (D.) Don. forest, most of the Ca and P were returned to the soil through leaf fall and Na through leaf leaching. For K and Mg, the amounts returned to the soils through leaching were equal to those returned through leaf fall.

Fifty to sixty percent of nutrient elements taken up by forest trees were accumulated in the wood and 15% to 20% in the green parts of the trees (Basilevich and Rodin, 1966). Thus much of the nutrients taken up were immobilized in the trees (Greenland and Kowal, 1960).

## Weed Problems in Pasture

Weeds and brush are common in tropical pastures and range lands. They cause losses by reducing pasture production and animal productivity. They are generally better competitors than pasture plants under low soil fertility and under heavy grazing. As such, they generally become dominant in a deteriorating pasture area. Some species are poisonous to livestock, and others are unpalatable. Thus, they are not grazed by livestock. Some weed species are readily grazed by cattle, but their dry matter production and nutritional qualities are low. Weeds and brush are therefore undesirable in the pasture areas.

Species of weeds in pastures. In the tropics and especially in Hawaii, common pasture weeds can be grouped into three types: the grass, the herbs and the tree (woody) types. The grass and the herbaceous weeds generally are the first to invade a pasture. At a later stage of pasture deterioration, the trees take over and become dominant.

Younge (1961) reported that knotroot foxtail and ricegrass paspalum dominated pangolagrass pastures in wetland areas in Hawaii. Other weeds such as sour paspalum, tropic ageratum [*Ageratum conyzoides* L.] and spreading dayflower were also common in Hawaiian pastures (Holms *et al.*, 1977). A herbaceous biennial, Hawaiian elephantfoot was widespread in pastures of Kauai and on the island of Hawaii (Nicholls and Plucknett, 1972). Motooka *et al.* (1967a) listed and discussed all the common weeds found in pasture areas of Hawaii. The weeds included lantana, Hamakua pamakani [*Eupatorium riparium* Regel], Christmas-berry tree [*Schinus terebinthifolius* Raddi], hairy fleabane [*Pluchea odorata* (L.) Cass.], Java plum [*Syzygium cumini* (L.) Druce], vervain, downy rosemyrtle [*Rhodomyrtus tomentosa* Wight], melastoma, Hawaiian blackberry [*Rubus penetrans* Bailey], firebush [*Myrica faya* Ait.], sourgrass [*Trichachne insularis* (L.) Nees], cats claw [*Caesalpinio sepiaria* Roxb.] and guava. Guava spread very fast in the pastures because of its prolific reproductive capacity and vigorous growth habits (Moomaw and Ripperton, 1958). In the study on improved tropical pasture in Kauai, Nicholls (1972) found most of these weed species in his pasture.

Factors affecting weed infestation. There are two main factors influencing the encroachment and spread of weeds in tropical pastures. They are overgrazing and low soil fertility. Although climate does influence weed spread to a certain extent, the species of pasture chosen for an area normally are adapted to the weather conditions of the particular area. However, overgrazing particularly in severe drought enhanced pasture deterioration (Chippendale, 1963; Condon *et al.*, 1969) and indirectly aided in weed infestation.

In irrigated nitrogen-fertilized pastures in Queensland, rapid spread of heartleaf drymary [*Drymaria cordata* (L.) Willd.] occurred in pastures which had been denuded by overgrazing (Elder, 1975). In a grazing trial under oilpalm in Malaysia, the sown species of stylo and guinea grass disappeared from the pasture after seven months of heavy grazing at four cattle/ha. The native grass such as sour paspalum, *Axonopus compressus* (Sw.) P. Beauv., and *Ottochloa nodosa* (Kunth) Dandy dominated the pasture. Even at two cattle/ha, there was a substantial increase in weedy species such as melastoma, *Eupatorium odoratum* (Linn.), and tropic ageratum (Anon., 1976). In Hawaii, Nicholls (1972) reported that lantana, guava, spreading dayflower, sour paspalum and knotroot foxtail increased after each controlled grazing. But when the pasture was allowed to rest, the weeds were smothered by the more responsive improved pasture species. This suggested that under continuous heavy grazing, these weed species would become dominant in the pasture. In Taiwan, Wang (1969) showed that continuous grazing and burning were the two most important factors influencing the encroachment of bracken fern in a tropical pasture. He also noted that the most successful competitors against weeds were paragrass [*Brachiaria mutica* (Forsk.) Stapf.], pangolagrass, Alabang-X [*Andropogon nodosus* (Willem.) Nash.] and African bluegrass [*Digitaria pentzii* Stent], in that order. Among the legumes, centro, peuro, oneleaf clover [*Alysicarpus vaginalis* DC.], leucaena [*Leucaena leucocephala* (Lamb.) de Wit], stylo and sweet clover [*Melilotus alba* Desr.] were the successful competitors.

The long term effect of grazing on tropical grass/legume pastures was reported by Bryan and Evans (1973). With time, there was a marked decrease in legume components accompanied by an increase in weeds. Intortum and silverleaf desmodium disappeared from the pasture under high stocking rate, and the weed species carpetgrass [*Axonopus affinis* Chase] became prominent after the sixth year. Sedge populations reached their peak on the sixth year and declined thereafter.

Williams (1968) had indicated that exclusion of stock from a degraded pasture or range land was useless if the pasture species had disappeared, but deferred grazing could lead to regeneration of the pasture if some of the desirable species were present.

Decline in soil fertility favors the weeds which have low fertility requirements for growth. The shift in weed population due to changes in phosphorus levels in the soils was shown by Hoveland *et al.* (1976). At low phosphorus level, crotalaria's growth was superior to Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] because Florida beggarweed had a higher phosphorus requirement. However, as phosphorus levels were raised, the competitive advantage shifted in favor of Florida beggarweed, because the latter was more responsive to phosphorus than crotalaria. Bruce (1972) also found that in a pasture mixture of stylo, molasses grass and guinea grass, weeds became dominant only in plots which were not fertilized with superphosphate. The shift or succession of pasture plants was also reported by Cooper (1932) with Kentucky bluegrass [*Poa pratensis* L.] pasture in which weeds replaced bluegrass when soil nutrients were low.

*Weed control in pastures*. Good management of the pasture is a preventive control measure by itself. Maintenance of vigorous growth of pasture species by using fertilizer was effective in controlling the spread of weeds (Hawton *et al*., 1975). Mowing the herbaceous weeds before they produce seeds is also effective if the infestation is not widespread. Another method is to use older cattle to graze the unpalatable weedy grasses.

The use of herbicides is effective in controlling many weeds. Encroachment of *Acacia* trees in the grassland areas of South Africa was controlled by applying paraffin or diesel oil onto the collars of these trees (Scott, 1967). The use of 2,4-D [(2,4-dichlorophenoxy) acetic acid], 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] and silvex [2-(2,4,5-trichlorophenoxy) propionic acid] to control woody and herbaceous weeds in pastures and range lands have been well documented (Little and Ivens, 1965; Motooka *et al*., 1967b and 1967c; Nicholls *et al*., 1971; and Scott, 1967). Control of grass weeds in stylo pasture establishment was achieved with the use of DCPA [dimethyl tetrachloro-terephthalate] at 6.7 kg a.i./ha preemergence, or benefin [N-butyl-N-ethyl-a,a,a-trifluoro-2,6-dinitro-p-toluidine] at 2.2 kg a.i/ha incorporated, or trifluralin [a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine] at 4.5 kg a.i/ha incorporated (Wood, 1970). Even at a lower rate (4.5 kg a.i/ha), DCPA gave excellent control of grass weeds (Fisher and Ives, 1970).

In Hawaii, effective use of herbicides for jungle conversion to pastures have been reported by Motooka et al. (1967a, b, c). These papers reported the control of brush species of lantana, melastoma, guava, ohia [Metrosideros collina subspecies polymorpha (Forst.)] and a fern, false staghorn fern [Dicranopteris linearis (Burm.) Underw.]. Earlier work by Moomaw and Ripperton (1958) showed that guava could be controlled with 2,4-D and 2,4,5-T, singly or in combination. Brush control research in pastures from 1965 to 1971 was reviewed by Nicholls et al. (1971). They concluded that systemic herbicides such as 2,4-D, 2,4,5-T, fenoprop [2-(2,4,5-trichlorophenoxy) propionic acide], picloram [4-amino-3,5,6-trichloropicolicin acid] and dicamba [3,6-dichloro-o-anisic acide] were efficient and effective in controlling guava, melastoma, Christmas-berry, Java plum, hau [Hibiscus tiliaceus L.] and firebush. Elephantfoot, another noxious weed of pastures, was best controlled by a combination of mowing and spraying with a mixture of 2,4-D and 2,4,5-T (Nicholls and Plucknett, 1972).

Biological control has also been used to control some weed species in Hawaii with good results. These weeds included lantana, pamakani [Eupatorium adenophorum Spreng.], tree cactus [Opuntia megacantha Salm-Dyck], emex [Emex spinosa Campd.], true puncture vine [Tribulus terrestris L.] and nohu [Tribulus cistoides L.] (Nakao, 1967).

Another successful method was the use of fire. But this method was restricted to false staghorn fern and gorse [Ulex europaeus L.] in Hawaii (Motooka et al., 1967a).

# MATERIALS AND METHODS

## Description of Study Area

Location. The study was conducted on a 6 hectare pasture area adjacent to the Hawaii Agricultural Experiment Station, Kauai Branch, Kapaa, on the island of Kauai. The pasture covered two steep-sided slopes facing north and south. A valley which runs approximately east and west separates the two slopes. Four line transects were established from the top of north (south-facing) slope to the top of south (north-facing) slope. Data on pasture and weed species distribution were collected along as well as across these transects. Also, soil samples were taken along these transects.

Soil. The pasture is on a highly weathered soil of the Halii series. It is a member of the clayey, ferritic, isothermic family of Typic Gibbsihumox. The soil developed from materials weathered from basic igneous rock and volcanic ash. The soil is dark brown with a granular structure and contains high proportions of gibbsite (or bauxite). The surface layer has high organic matter, low cation exchange capacity, low base saturation and low pH. The soil has a high phosphorus adsorption capacity and plants respond favorably to phosphate application.

Climate. The Kauai Branch Station is approximately 180 meters above sea level, with an average annual rainfall of 2050 mm. The mean maximum temperature is 25°C and the mean minimum is 19.5°C. There is distinct pattern in the rainfall distribution; a maximum during the winter months and a minimum during the summer months (Figure 1).

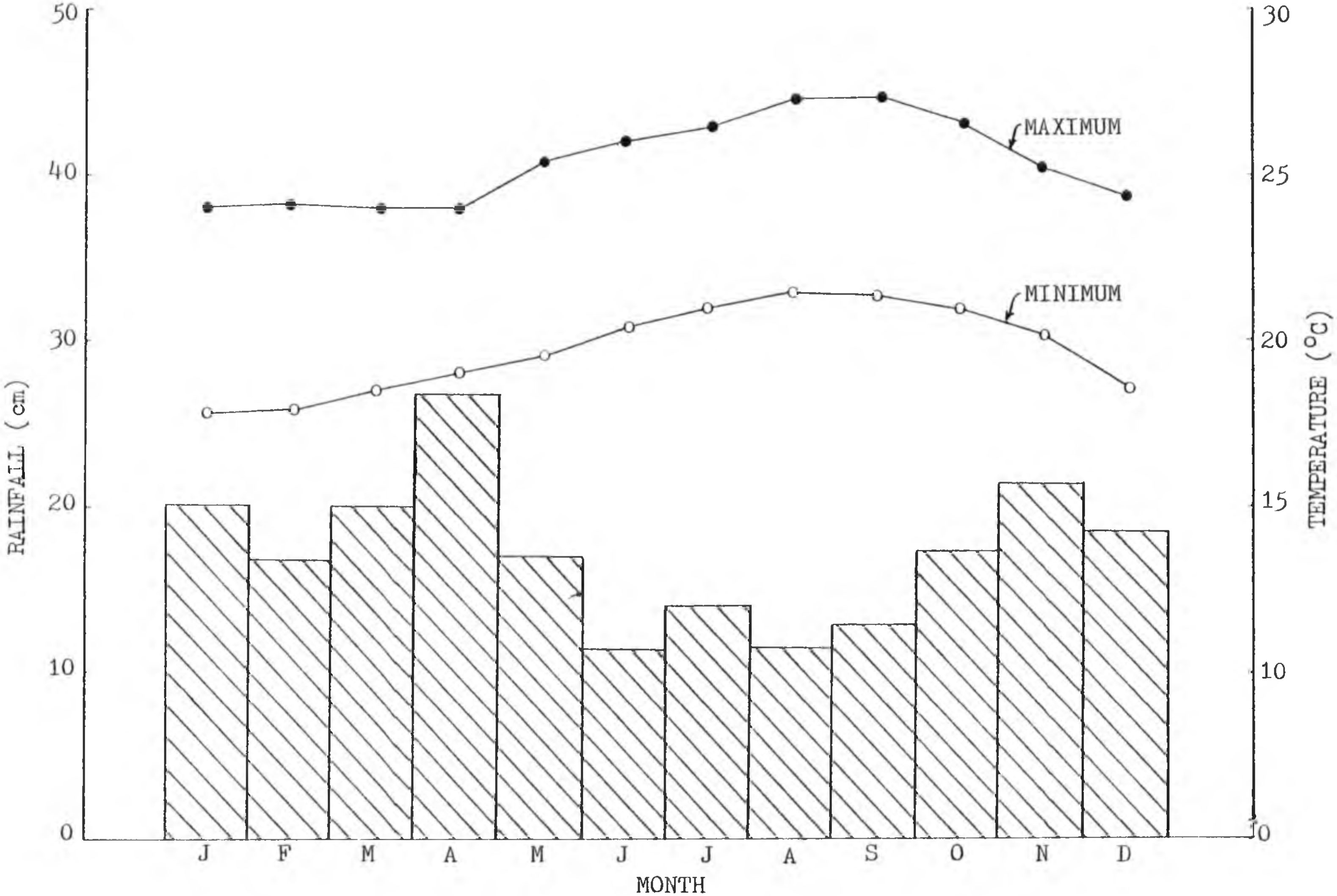


Figure 1. Average monthly temperature and rainfall at Kauai Branch Station from 1970 to 1977.

Variation in temperatures between January and July is about 3°C. The prevailing wind is northeasterly, blowing most of the year. The strong southerly wind prevails during January through March.

History. Prior to pasture development in 1966, the area was a jungle. The vegetation was made up of false staghorn fern, lace fern [*Stenoloma chinensis* (L.) Bedd.], Boston fern, tree fern [*Sadleria* sp.], Pandanus [*Pandanus odoratissimus* (L.f.)], melastoma, ohia, guava, Java plum, hau, downy rosemyrtle and lantana. These vegetations were reported by Moomaw and Takahashi (1960), Motooka *et al*. (1967b), and Nicholls (1972). The last two reports also described the subsequent jungle-to-pasture conversion work.

In 1966, following two aerial applications of 4.48 kg/ha of silvex and burnings, seeds of tropical pasture grasses and legumes were sown by air, together with 224 kg/ha treble superphosphate. All the legumes were inoculated with the appropriate *Rhizobia*. In 1967, after a 13 month establishment period, the pasture was grazed occasionally for two years. In 1970, the pasture was rotationally grazed, until 1973 when the area was leased. Recorded fertilizer applications were made three times. Application in 1966 consisted of 224 kg/ha of 18:40:0 and application in 1968 and 1970 each consisted of 224 kg/ha of 7:30:20.

A thorough ecological study of vegetation and environmental factors of the pasture area was made by Nicholls (1972). The dominant pasture species present were stylo, intortum, green panicgrass and pangolagrass. Pangolagrass was planted along the top of north (south-facing) slope from cuttings. The weedy species were dominated by sour paspalum, knotroot foxtail and spreading dayflower. Less prevalent species were Hawaiian elephantfoot, American burnweed, lantana, melastoma and nettleleaf vervain.

The pasture was continuously grazed since 1973, and the last recorded application of fertilizer was made in 1970. The pasture species therefore had been subjected to continuous pressure. The decline in soil fertility, frequent defoliation, and trampling would influence the survival, distribution patterns, and productivity of pasture species, as well as the encroachment of weedy species.

## Methods of Study

Transects. In 1970, 13 transects were established by Nicholls (1972) in the 20 hectares of pasture area (Figure 2). All the transects run from the top of north slope to the top of south slope and were parallel to one another. In addition, transects T1, T2, T3 and T4 were equidistant, at 60 meters apart. The lengths of these four transects varied from 200 meters to 250 meters. Ten steel posts, five on each slope, were located on each of these four transects. The first post on top of the north slope was at the same elevation as the first post on top of the south slope, and so on down the two slope aspects. The 40 posts were used as the reference points for taking soil samples and for collecting data on vegetation distribution patterns and pasture productivity. Nicholls (1972) used the same reference points for his ecological study.

Sampling for species distribution. The belt transect method described by Nicholls (1972) was used for sampling. This method was

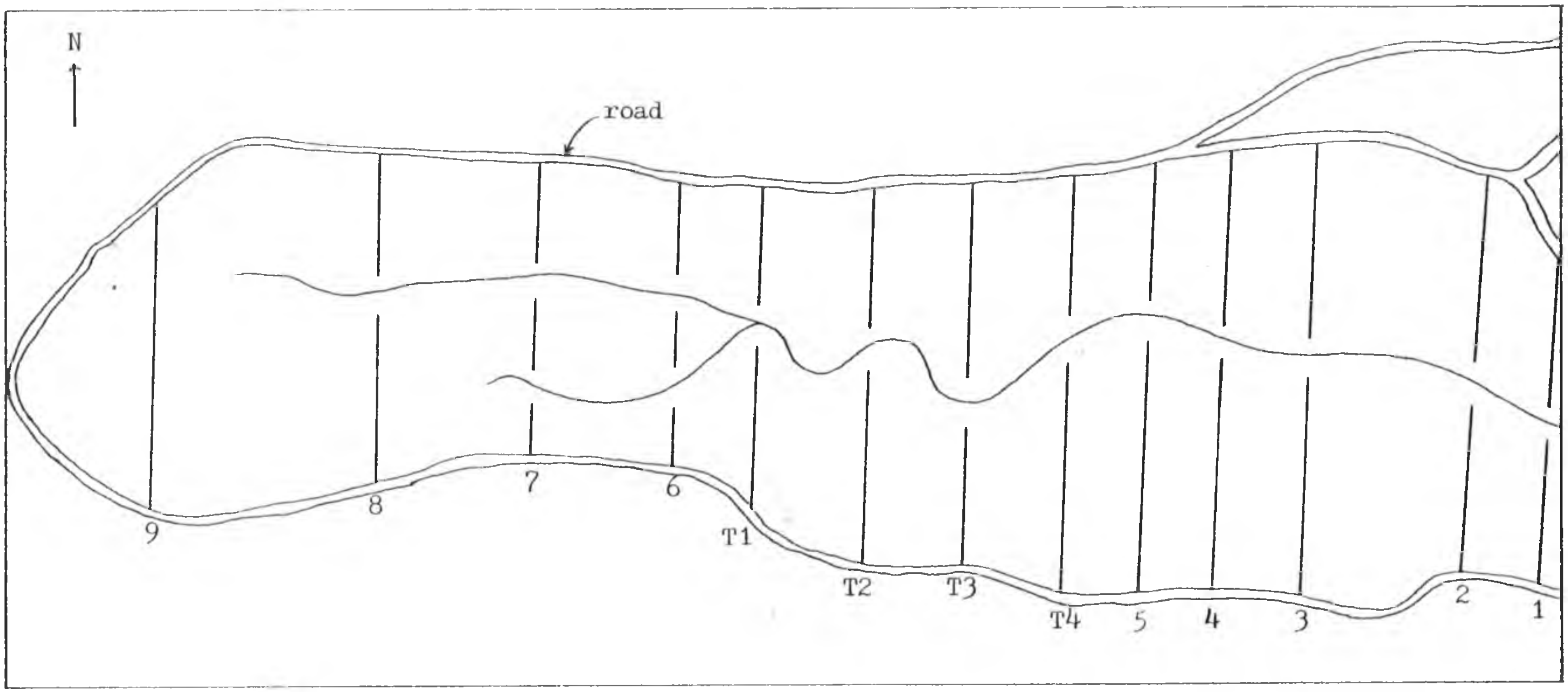


Figure 2. Aerial diagram of pasture area showing locations of sampling transects. Road runs along the tops of north and south slopes. The creek represents the valley bottom.

Figure 3: The overall view of the pasture area. The north and south slopes are on left and right hand sides, respectively. Note the thick growth of woody trees.

made up of 'rolling' a one-meter square quadrat (1 m x 1 m) along the transect line as well as across each transect line at the reference point. The presence and absence of pasture and weed species were recorded.

On July 6, 1978, sampling of species distribution along the transect lines was made from the top of the north slope to the top of south slope. The data were used for mapping the patterns of distribution of stylo, intortum, green panicgrass, sour paspalum-knotroot foxtail association and spreading dayflower.

On July 14, 1978, and again on September 26, 1978, 60 quadrats were sampled across each transect at each reference point 30 quadrats on either side of the transect. The data were used to determine the frequency distribution of all the species present.

Sampling for pasture productivity. The dry-rank method of 't Mannetje and Haydock (1963) was used for sampling the dry matter contribution of each pasture species. At each quadrat position, the pasture and weed species that contribute to feed were ranked 1, 2, or 3, based on visual estimate of their dry matter. The total number of 1, 2, and 3's were multiplied by common factors of 70.2, 21.1 an 8.7, respectively. From this, the percentage of each species in the pasture was calculated. Thirty quadrats were sampled on each side of the transect. This sampling was done in July and also in October 1978.

Dry matter sampling was done in July and October 1978 using the destructive method. At each reference point, 20 squares were located on a 2-meter square grid. Two of these squares were taken randomly at each harvest. For the second harvest, another two samples were randomly chosen from other than those already harvested in the first sampling. All species were harvested at 2.5 cm above ground level. The samples from each reference square were bulked, sorted into species, oven-dried at 49°C and weighed after 24 hours.

Sampling for soil. On July 25, 1978 and again on October 5, 1978, soil samples were taken of the study area using an auger of 12 cm diameter to a depth of 20 cm. At each reference point, four soil cores were dug one meter to the north, south, east and west of the steel post. Another core was taken about 0.5 meter from the post. These five samples were bulked, mixed thoroughly in a plastic pail and subsampled into a plastic bag. The subsamples from 40 reference points were used for the determinations of soil moisture, pH and for analyses of extractable phosphorus, and exchangeable calcium, potassium and magnesium.

Soil measurements. Except for the determination of soil moisture, all the soil samples were first air-dried for one week and sieved through a 20-mesh screen, prior to making pH measurement and nutrient analyses.

Soil moisture: Determination was carried out using the fresh samples immediately after sampling. The oven-dried method was used. Fresh soil was half-filled into a moisture can, weighed and dried in the oven at 105°C for two days. The final weight was recorded when the soil showed a constant weight. To make sure that no moisture was lost from or absorbed into the soil when it was out of the oven, the can was always tightly covered with a lid. Each soil sample was done in duplicate.

Soil pH: pH measurement was taken from a 1:1 soil-water slurry using an Orion Research meter. Fifty grams of soil were placed in a plastic cup, and 50 ml of distilled water were added and mixed thoroughly to form a slurry. Measurement was made after allowing the slurry to equilibrate for 24 hours.

Nutrient analyses: Determination of extractable phosphorus was made using the modified Troug method. Exchangeable calcium, potassium and magnesium were determined using the atomic absorption spectroscopy method. Both methods are given in Appendix A. Moisture factor was determined for each sample during the analyses.

<u>Other samplings</u>. Since much of the area was overgrown with thickets and trees, fresh yields of dominant species, namely lantana, melastoma and guava were taken. Ten quadrats of one square meter each were randomly chosen from transect T3 and harvested. Each sample was sorted into the three species and weighed.

The percentage of visible light passing through the canopies of lantana, melastoma and guava were measured using 'Sol-a-meter'. The meter reading was adjusted to 100% with direct sunlight. Readings in the canopy were taken at 0.5 meter apart, starting from the base (trunk) of the tree in the north, south, east and west directions.

# RESULTS AND DISCUSSION

## VEGETATION DISTRIBUTION

### Dominant Species

In 1971, the pasture was dominated by stylo, intortum, green panicgrass, sour paspalum, knotroot foxtail and spreading dayflower (Nicholls, 1972). In 1978, the dominant species had changed, as shown in Table 1. Weed species made up most of the vegetation of the pasture. Of the improved pasture species, intortum had disappeared and pangolagrass had increased in number and spread (as will be shown later). Weed species of Hawaiian elephantfoot, Boston fern, sour paspalum and glenwood grass had become the four most widespread species in the pasture area.

The pasture species of stylo, intortum and green panicgrass contributed most to the feed for the cattle in 1971 (Nicholls, 1972). These species contributed over 10,000 kg/ha of dry matter on offer before each grazing period. However, the yield decreased to 1000 to 2000 kg/ha after grazing, and when grazing was discontinued for three months, the pasture yield returned to the original value. In 1978, the yield on offer of these improved species combined was so low (192 kg/ha) that other grassy weeds might have contributed as feed for the grazing cattle (Table 2). Melastoma, lantana and guava shrubs covered 37.6% of the pasture area and these species produced the most vegetation biomass, as shown in Table 2. But they were not grazed by the cattle.

Table 1: The probability (expressed as percentages) of finding these species in the pasture area in 1978, using a 1 x 1 meter quadrat.

| species | type | % |
|---|---|---|
| Hawaiian elephantfoot | herbaceous | 75.0 |
| Boston fern | fern | 68.6 |
| Sour paspalum | grass | 64.3 |
| Glenwood grass | grass | 62.1 |
| Stylo | pasture legume | 43.7 |
| Knotroot foxtail | grass | 42.0 |
| Melastoma | shrub | 36.7 |
| Lantana | shrub | 35.1 |
| Green panicgrass | pasture grass | 33.5 |
| Nettleleaf vervain | shrub | 33.4 |
| Ricegrass paspalum | grass | 29.3 |
| Pangolagrass | pasture grass | 27.0 [a] |
| Guava | shrub | 20.6 |
| Sensitive plant | herbaceous | 19.3 |

[a] found only on north slope

Table 2: Yield of pasture and weed species in October 1978.

| | | Dry weight (kg/ha) | Fresh weight (kg/ha) |
|---|---|---|---|
| a. Pasture species | | 192 | 762 |
| b. Weeds: | Grasses and legumes | 323 | 1,282 |
| | Boston fern | 235 | 951 |
| | Elephantfoot | 156 | 611 |
| c. Shrubs: | Lantana | - | 21,020 |
| | Guava | - | 7,740 |
| | Melastoma | - | 7,380 |

a, b: calculated from 80 samples.

c: calculated from 10 samples.

## Distribution Patterns of Species in 1971 and 1978

There has been a succession of species in the pasture since the last sampling in 1971. Improved pasture species have been replaced by weeds which were better adapted to the deteriorating soil fertility and overgrazed conditions of the pasture area. This section will therefore deal with the changes in the distribution patterns of a) the dominant species in 1971, and b) the indicator weed species of pasture deterioration, as indicated by Nicholls (1972). The distribution patterns of other dominant species in 1978 will also be discussed.

Dominant species in 1971. The diagrammatic representation of distribution patterns of stylo, intortum, green panicgrass, sour

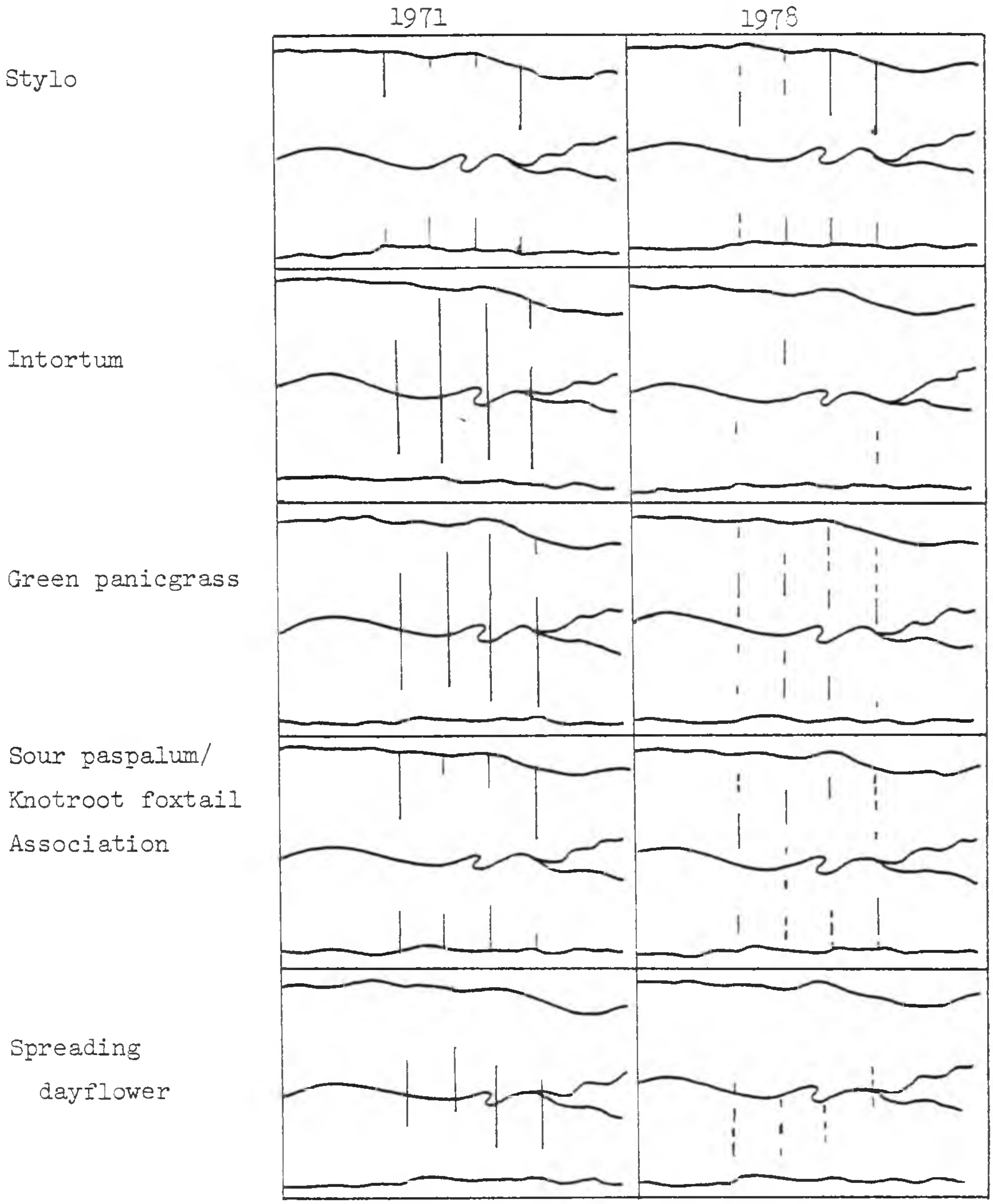


Figure 4: The distribution patterns of dominant pasture and weed species in 1971 (left diagram) and in 1978 (right diagram) along the four sampling transects, T1, T2, T3 and T4. The straight line or a dash represents the location where the species was recorded.

Key:


top of south slope

creek (valley bottom)

top of north slope

paspalum-knotroot foxtail association and spreading dayflower in 1971 (Nicholls, 1972) and 1978 are shown in Figures 4 and 5. In Figure 4, the straight line or a dash represents the location where the species were recorded along the four sampling transects. Figure 5 shows the frequency distribution of these species along the transects at each reference point (marked by A, B, C, ... etc.). The trends in species distribution along the transects are shown statistically in Appendix Table 3 using BLSD. With reference to these figures and table, the distribution patterns of each species are discussed.

Stylo: In 1971, stylo was abundant on top of north and south slopes, extending half-way down the south slope along transects T1 and T4 (Figure 4). In 1978, stylo was found on lower parts of the south slope along all four transects, as well as on lower parts of the north slope along transects T1 and T4 (Figure 4). This 'movement' of stylo down the slope is clearly shown by the frequency distribution diagram (Figure 5). In July 1978, stylo was flowering and producing seeds. During this unexpectedly wet month, stylo seedlings were found on bare patches as well as between the weedy grass of ricegrass paspalum. Its ability to germinate and grow in the open or under poor light condition may have contributed to its survival and spread. The movement of stylo seeds down the slope is due to cattle and also seeds falling down the slope. Cattle grazing on stylo may ingest the ripe stylo seeds as well and movement of cattle up and down the slope helped to spread the dung which contain viable seeds.

Although stylo had spread to lower areas of the slope, its contribution to cattle feed was low because stylo grew close to the ground as

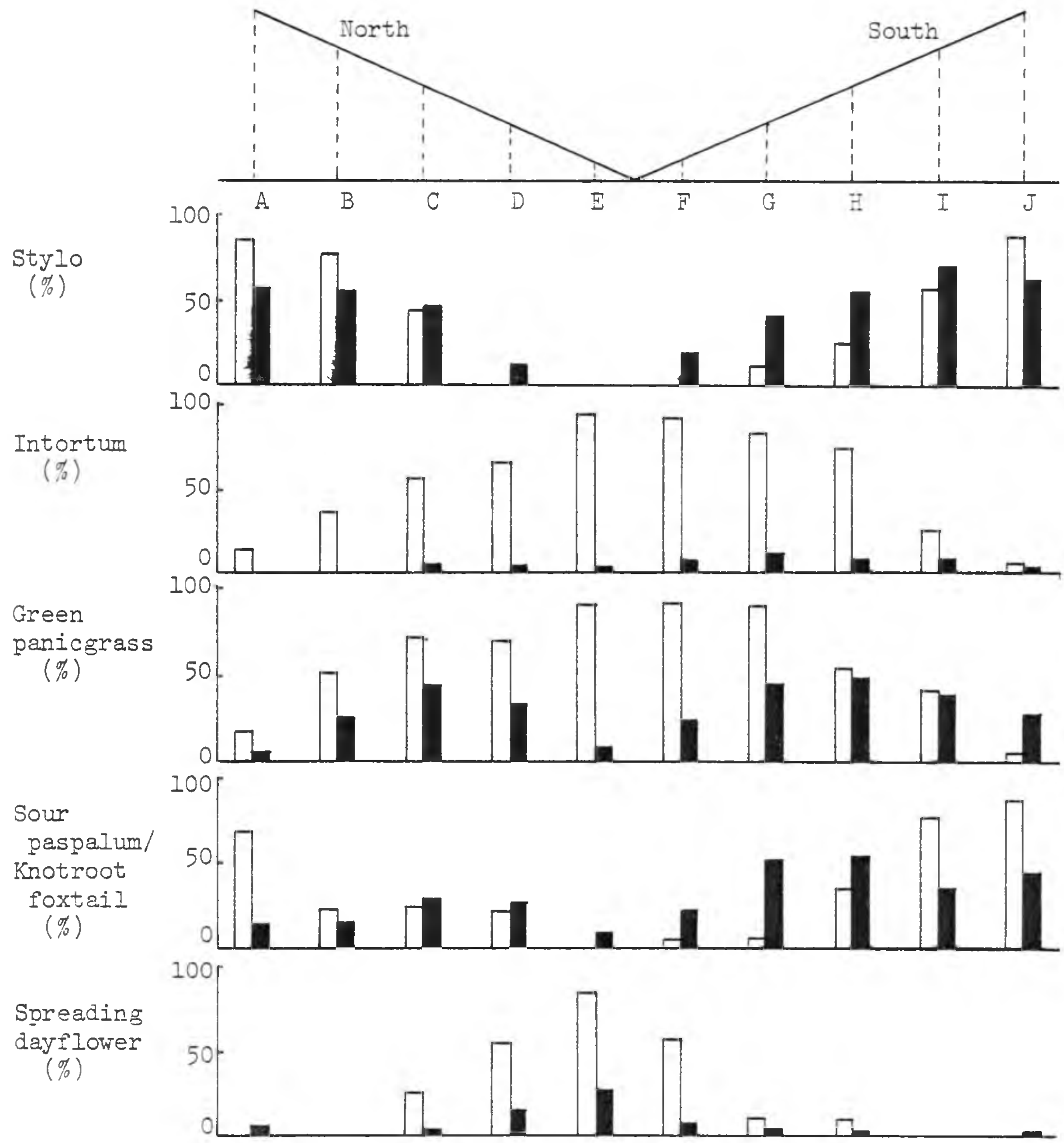


Figure 5: The frequency distribution of dominant pasture and weed species of 1971 (unshaded), and their distribution in 1978 (shaded) along the north and south slopes.

the result of continuous grazing. During the October 1978 sampling, six to nine cattle were grazing in the area. The dry matter on offer was 100 kg/ha, as compared to about 1000 kg/ha after grazing in a relatively good pasture situation in 1971.

Intortum: In 1971, intortum was one of the main species for cattle feed. It was well distributed throughout the pasture (Figure 4), with greater frequency towards the bottom of the slopes and the valley bottom. Because of its high palatability, the species was readily grazed by cattle. By 1978, intortum had almost disappeared from the pasture (Figure 5). In fact, the species was only found growing under melastoma and lantana thickets where it was protected from grazing. Overgrazing was one of the factors contributing to the disappearance of this species from the pasture. Intortum is suceptible to low soil phosphorus (Sanchez, 1976). Its critical P level in tissue is 0.22% (Andrew and Robins, 1969a) which is higher than that of stylo (0.16%) (Bruce, 1974). Soil analysis of the pasture area showed an extremely low soil extractable P. This suggests that low soil P may be one of the factors affecting intortum's disappearance from the pasture.

Green panicgrass: In 1971, green panicgrass was well distributed throughout the pasture, and its pattern of distribution closely followed that of intortum (correlation coefficient r = 0.80**) (Figures 4 and 5). This species dominated the lower parts of the slopes and the valley bottoms. These areas had higher soil moisture and nutrient status than other parts of the slope (Nicholls, 1972). In 1978, its distribution pattern had changed. More green panicgrass was found on the middle sections of the slopes and decreased towards the top and bottom of the slopes. This distribution pattern closely followed those of melastoma (r = 0.40**) and lantana (r = 0.50**) (Figure 6). It was observed that green panicgrass was growing in melastoma and lantana thickets, and on steep areas of the slopes. In these areas, cattle could not graze the grass because of the difficulty in getting to the plant. Thus, it was not grazed. Green panicgrass was sometimes found growing in the open, but its growth was stunted, probably due to constant grazing and declining soil fertility. Its contribution to cattle feed was negligible.

Sour paspalum-knotroot foxtail association: In 1971, this sour paspalum-knotroot foxtail association was distributed from the top to the middle sections of north and south slopes (Figures 4 and 5). Nicholls (1972) showed that this association followed the same distribution pattern of stylo (with a correlation coefficient of 0.78**).

In 1978, sour paspalum was found along the slope, with increasing frequency towards the valley bottom. In contrast, knotroot foxtail dominated the middle section of the slope with decreasing frequency towards the top and bottom of the slope (Figure 10). Thus, these two species did not have the same distribution pattern. This is shown by the low correlation coefficient value (r = 0.16). Therefore, under deteriorating pasture conditions, these two species did not appear to grow in association.

Although sour paspalum and knotroot foxtail are normally not grazed under good pasture conditions, it can contribute to the total feed for the cattle.

Spreading dayflower: Spreading dayflower was confined to the valley and lower parts of the slopes, particularly the north slope, as shown in Figures 4 and 5. In 1971, it was abundant at the valley bottom. In 1978, the north slope was covered by thick mealstoma and lantana thickets from the top to the middle section of the slope, and by thick guava stands towards the bottom of the slope. Spreading dayflower was mostly found growing under shade of these woody shrubs. Being palatable, it is readily grazed by cattle. But these areas on the north slope were not easily accessible by the cattle. The south slope was more open and therefore spreading dayflower was available for the grazing cattle. Its disappearance from the lower south slope could be attributed to grazing.

Nicholls (1972) showed that the distribution of this species was positively correlated to soil pH, moisture and soil P. Soil P in 1978 was very low, 4.7 ppm compred to 14 ppm in 1971. Soil P could also be a contributing factor to the decline of this species in the pasture.

On the whole, grazing appeared to have an overwhelming influence on species distribution. Certain palatable species like spreading dayflower grew well under shade of and protection from grazing animals due to shrubs, while being grazed in other areas. Other palatable species like intortum did not grow well with reduced light and could not compete with the unpalatable species.

<u>Indicator weed species of 1971</u>. In addition to sour paspalum-knotroot foxtail association as a reliable indicator of deteriorating pasture conditions, elephantfoot, lantana, melastoma, American burnweed and vervain were also good species indicators (Nicholls, 1972). Their

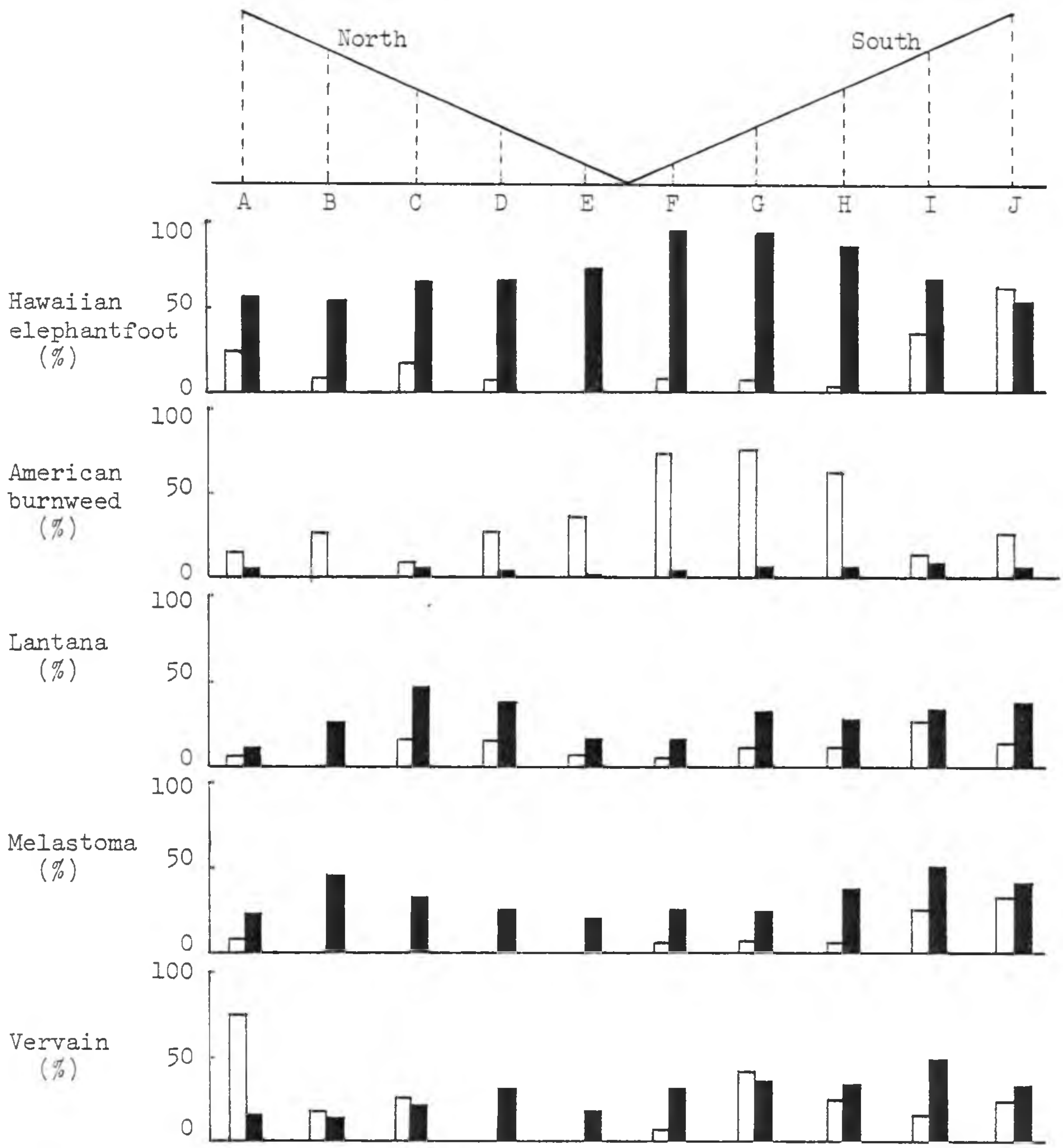


Figure 6. The frequency distribution of some indicator weed species along the north and south slopes of the pasture in 1971 (unshaded) and in 1978 (shaded).

increase in number (occurrence) and spread indicated the deterioration in the pasture. Under good maintenance of soil fertility and proper grazing pressure, improved pasture species remained vigorous and competitive. If overgrazing and natural decline in soil fertility are allowed, these weed species of low fertility requirements and of less acceptability to cattle are favored in the shift of species. With time, these species will become the dominant components of the pasture, unless control measures are taken.

Figure 6 illustrates the distribution patterns of these indicator weed species in 1971 and in 1978. Two types of species response were observed: 1) increase in number (occurrence), and 2) decrease in number.

<u>Species that have increased in number</u>

All indicator species except American burnweed increased in number (Figure 6).

Elephantfoot had increased tremendously. It was found in large numbers all over the pasture area. This species was distributed more towards the south valley. The increase in this species was probably due to several factors. In 1971, the valley was dominated by green panicgrass, intortum and spreading dayflower. Elephantfoot may not have been competitive in 1971 because of higher soil nutrient levels which favored the pasture species. With the decline of soil fertility over time, the pasture species were less competitive and were replaced by weeds like elephantfoot. Being a prolific seed producer and not grazed by cattle, this weed spread rapidly and occupied the lower areas of the slope. Elephantfoot is also shade tolerant. Therefore it could grow under the canopies of guava, lantana and melastoma.

Lantana was distributed more towards the middle of the slope. Its spread of seeds was by birds which eat the fruits. Nicholls (1972) had shown that lantana spread rapidly under heavy grazing regimes, but when the pasture was allowed to rest, lantana could not compete with pasture species. Increase in lantana recorded in 1978 was largely due to overgrazing.

Melastoma increased throughout the pasture. In 1971, it was only found on top of north slope. Its spread to other parts of the north slope was due to the spread of seeds by birds and due to fruits falling to lower parts of the slope by gravity. Melastoma's unpalatability and competitiveness contributed to its increase.

Vervain had also spread throughout the pasture. In 1971, it was not present on the lower position of the north slope, but in 1978, it had occupied this area.

Species that have decreased in number

American burnweed was the only indicator species that decreased in number. It almost disappeared from the pasture, especially the lower parts of the south slope where in 1971 it was found most abundant. This annual weed was less competitive than other pasture weeds. American burnweed could not tolerate shading and was only found in the open in 1978. Nicholls (1972) noted that this species increased when soil moisture conditions were favorable and some bare grounds were available. However, under severe grazing pressure, this species was suppressed by trampling and grazing.

Figure 7: The different species growing amongst lantana shrub. These species include stylo, Boston fern and ricegrass paspalum.

Figure 8: Melastoma shrub with fern growing in association with it.

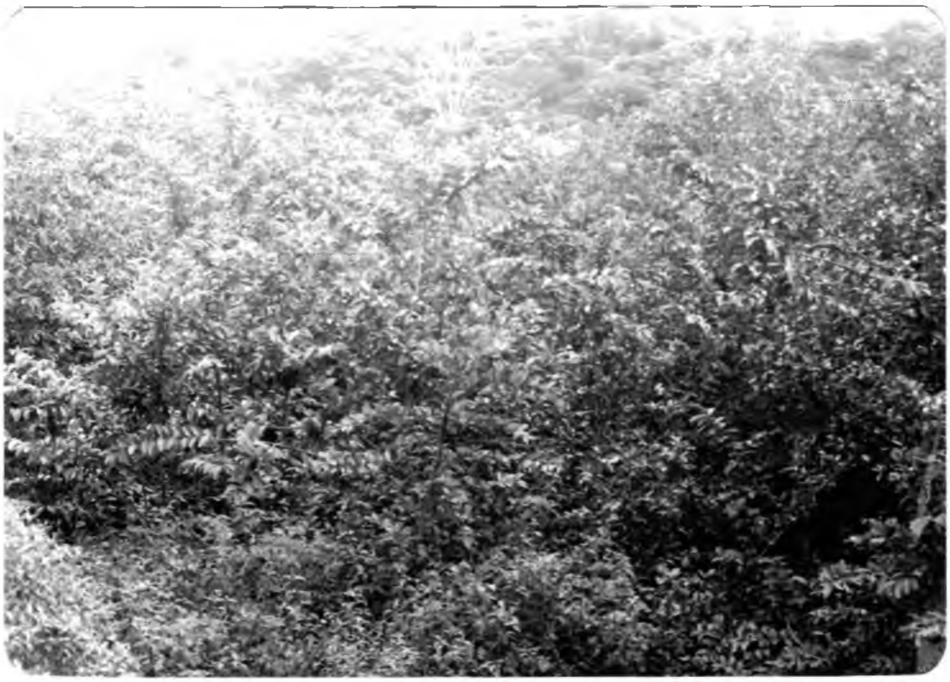

Figure 9: Thick guava stand at the valley bottom.

Of the indicator weed species described by Nicholls (1972) that signal a deteriorating pasture, one species, American burnweed, almost completely disappeared, while others dominated in 1978. Vervain increased slightly, melastoma and lantana increased substantially and elephantfoot increased the most from 1971 to 1978.

American burnweed was observed to be the first species growing in a burned area (Motooka et al., 1967b). Moomaw and Takahashi (1960) reported an increase of American burnweed after burning. The pasture area under study was burned in 1966 before sowing with pasture species. Therefore the presence of American burnweed in 1971 may be the result of burning and not necessarily a good indicator weed species of deteriorating pasture.

## Other Dominant Species of 1978

The dominant species in the pasture in 1978 are shown in Table 1. Besides weed species already discussed, Boston fern and glenwood grass were among the most prevalent species. Other dominant species were ricegrass paspalum, guava and pangolagrass.

Boston fern was well distributed throughout the pasture area (Figure 10). It was found growing amongst lantana ($r = 0.31^{*}$) and mealstoma ($r = 0.45^{**}$) thickets at the middle and top sections of the slope. Towards the valley bottom, Boston fern was growing under the canopy of guava. Melastoma, lantana and guava apparently provided the fern with the right habitat for its growth, i.e., reduced light and protection from trampling and grazing.

Glenwood grass was found throughout the pasture area. It dominated

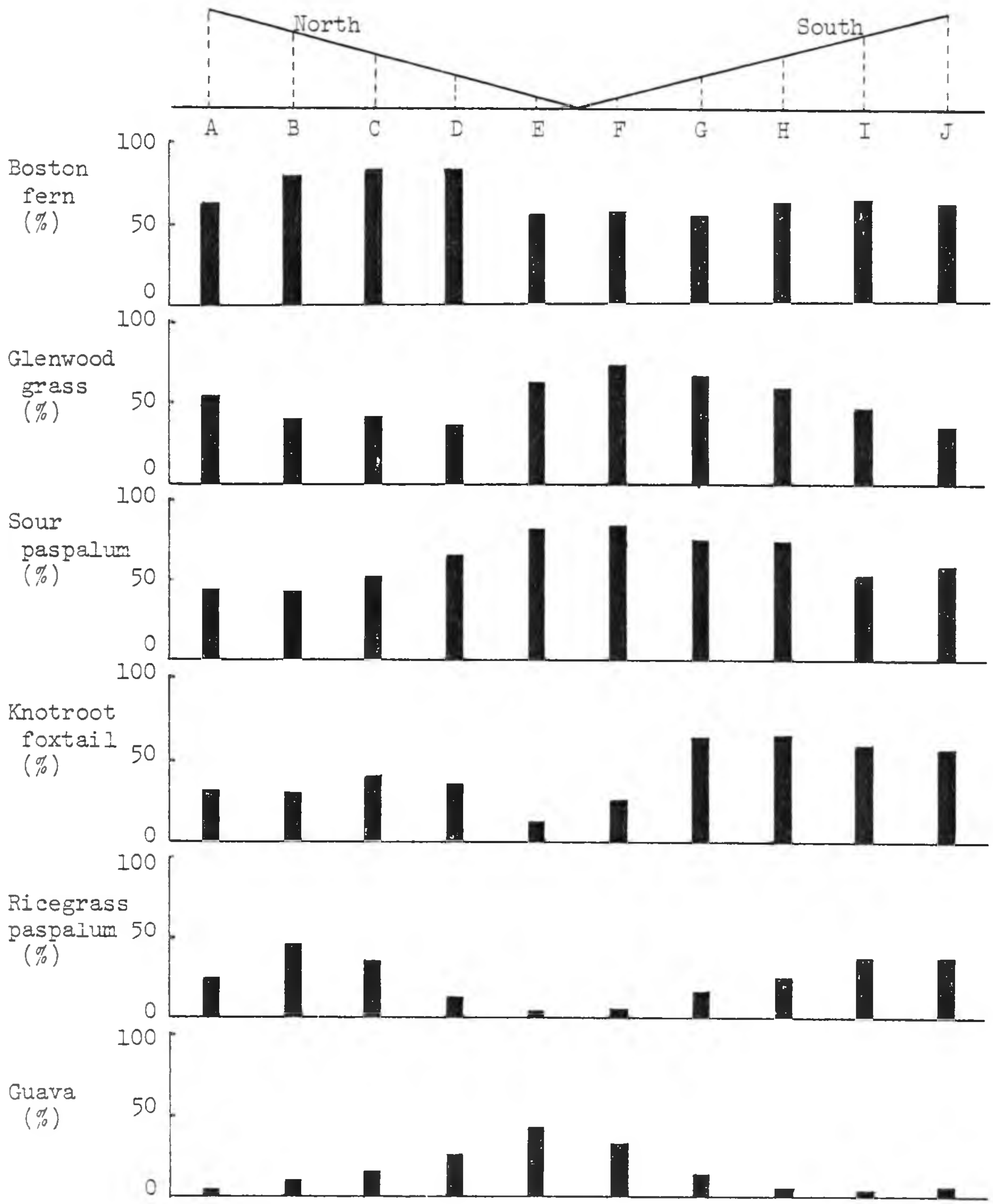


Figure 10: The distribution patterns of other dominant weed species along the north and south slopes. The distribution is expressed as percentage frequency of occurrence.

the open areas of south slope. It grew close to the ground (creeping) and therefore was not grazed by cattle. At the lower parts of both slopes, this grass also grew under the shade of guava. Here, it assumed an upright growth and reached a height of 30 to 50 cm. This grass was naturalized in this area (Moomaw and Takahashi, 1960). Its distribution follows that of sour paspalum ($r = 0.66^{**}$).

Guava dominated the valley bottom where it was adapted to the wet areas. In 1971, Nicholls (1972) reported that guava was confined to the valley bottom. Results of the 1978 sampling showed that this species had spread to the north and south slopes. Movement of guava up the slope, opposite that of stylo, was largely due to the spread of guava seeds by birds and cattle. The ripe fruits of guava are readily eaten by cattle. It was observed that a large number of guava seedlings were found where cattle dung had decomposed.

Pangolagrass was planted along the north slope. In 1971, Nicholls (1972) reported that this grass was only found along the top of north slope at transects T1 and T4. In 1978, pangolagrass was found at sites B, C, and even at sites D and E (Figure 11). This indicated that pangolagrass had spread down the slope. Pangolasgrass was also found along transects T2 and T3 (Figure 11). In 1971, this grass was not found on these transects (Nicholls, 1972). Therefore pangolagrass had also spread along the slope. The spread of this grass along and down the slope was probably due to its aggressive stolon production. Nicholls (1972) noted that mature pangolagrass was not readily grazed by cattle. This low acceptability was because of low levels of phosphorus and crude protein in the grass. Younge (1961) showed that in a pangolagrass-intortum pasture, pangolagrass recovered faster than intortum after harvest. These factors may also have contributed to its spread along and down the slope.

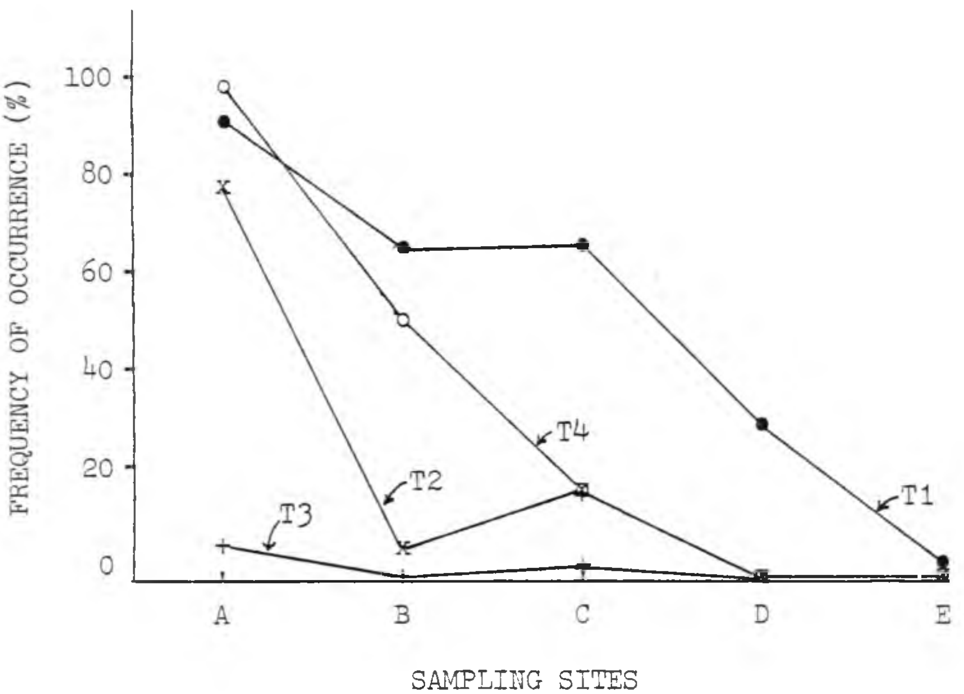


Figure 11. The distribution of pangolagrass (<u>Digitaria decumbens</u>) in 1978 along the four sampling transects of north slope. Site 'A' is at the top of north slope and site 'E' at the bottom of north slope.

<u>Species Response in Wet and Dry Periods</u>

The rainfall pattern of Kauai Branch Station from 1970 to 1977 showed a distinct dry period in June and July, and a wet period starting in October (Figure 1). But in 1978, June and early July were wet and September and early October were about normal (Appendix Table 1).

The response of pasture and weed species to changes in these abnormal weather conditions is shown in Table 3. Figure 12 illustrates

Table 3. The change in the population of each pasture and weed species between July and October samplings. The t-test was used to determine the change in species occurrence from July to October 1978.

| Species | Type | Change |
|---|---|---|
| American burnweed | herb | increase** |
| Boston fern | fern | increase* |
| Glenwood grass | grass | increase** |
| Green panicgrass | pasture grass | increase* |
| Guava | shrub | increase** |
| Hawaiian elephantfoot | herb | increase** |
| Knotroot foxtail | grass | no change |
| Lantana | shrub | increase** |
| Melastoma | shrub | increase** |
| Pangolagrass | pasture grass | no change |
| Ricegrass paspalum | grass | increase** |
| Sensitive plant | legume | increase** |
| Sour paspalum | grass | no change |
| Stylo | pasture legume | no change |
| Tarweed cuphea | herb | increase** |
| Tropic ageratum | herb | increase** |
| Vervain | herb | increase** |

* significant at 5% level

** significant at 1% level

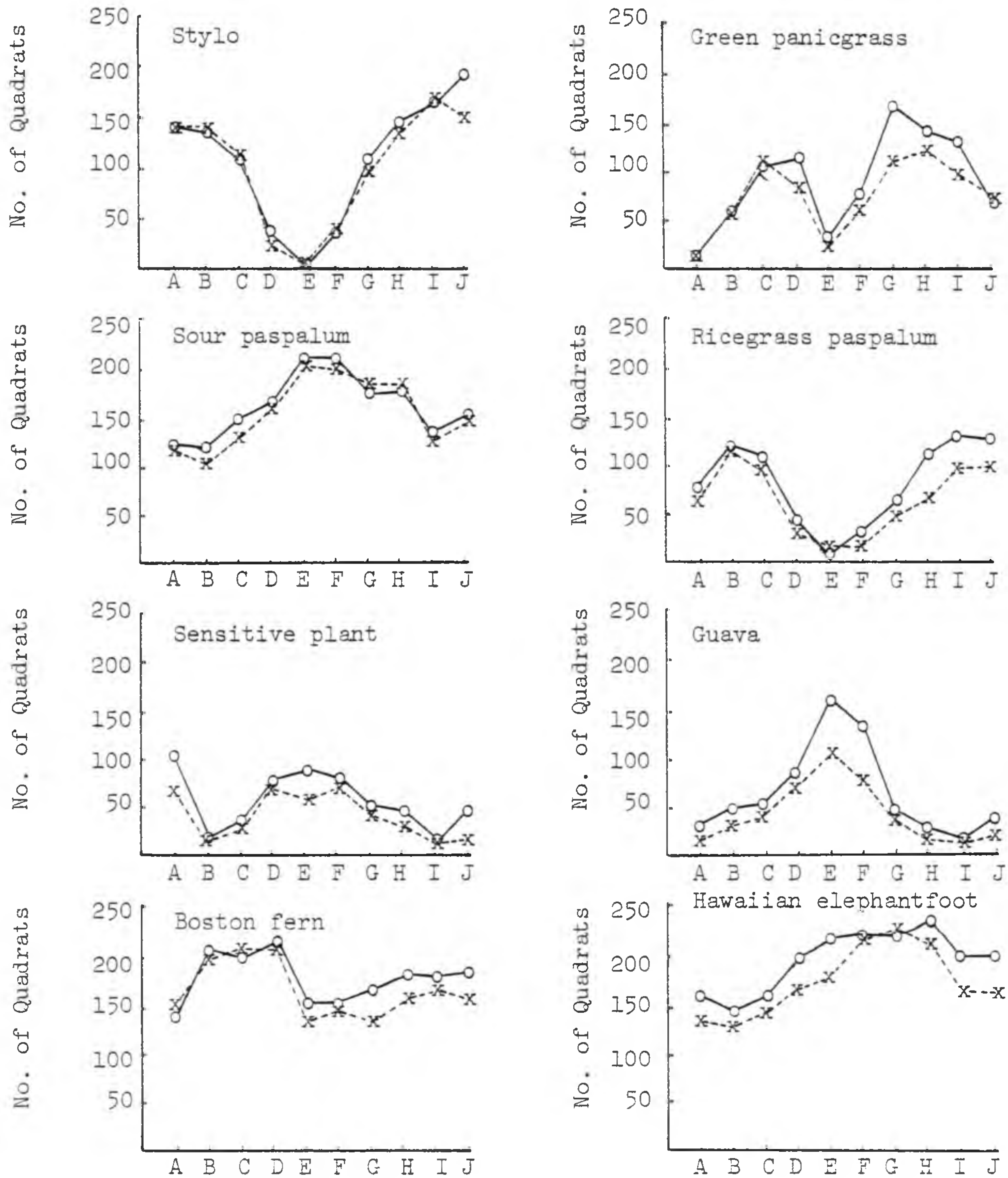


Figure 12: The distribution of pasture and weed species in July (broken lines) and in October (solid lines), across valley transects. Sites 'A' and 'J' are at the tops of north and south slopes, respectively.

the response of some of these species graphically. An increase indicates that the number of quadrats in which the species recorded in October was significantly higher than that of July. Except for sour paspalum and knotroot foxtail, all the other weed species showed an increase. This is partly due to high temperature and favorable moisture conditions in September and early October which were ideal for plant growth. The dry matter of pasture species in October also showed an increase compared to that of the July sampling. The pasture area was heavily infested with shrubs and thickets. During the July sampling, some of these shrubs and thickets had to be cleared to make way for sampling. This opened up the shaded area to sunlight, thus providing a better environment for the weed seeds to germinate and grow. Therefore, the increase may also be due to this 'clearing'.

Stylo, pangolagrass, sour paspalum and knotroot foxtail showed no change between October and July samplings. The possible reason is that since these species were the only species providing feed for the cattle in the pasture, they were being grazed continuously. As a result, any increase in October due to weather and 'clearing' was offset by the grazing. Therefore they showed no change.

Although green panicgrass is a pasture species of high palatability, its increase was due to the fact that cattle could not get to it since the grass was growing amongst melastoma and lantana thickets or on steep slopes.

(a)

(b)

Figure 13: The overgrazed pangolagrass on top of north slope. Note the good growth of pangolagrass in the background of both pictures where it is protected from grazing due to (a) steep slope and (b) lantana shrub.

## SOIL FACTORS

### Soil Moisture (% O. D. Soil)

Figure 14 shows the trend in soil moisture content along the valley transects. There was a significant increase in soil moisture as one goes down the slope. This trend was evident along all four transects.

There are several reasons to explain this trend. The main reason is the downward movement of drainage water through the surface horizon of the soil parallel to the soil surface. Also, the soil profile of surface horizon at the top of the slope was shallower than at the valley (Nicholls, 1972). Thus, soils at the top of the slope have a lower water storage capacity than soils of the valley. The drying effect of the wind at the top and the more humid, still conditions in the valley may also contribute to the trend.

The average moisture content of the soil along the transects in July was higher than that of October. This can be explained by the difference in rainfall between the two months. June and July were wetter than September (Appendix Table 1).

### Soil Nutrients

The soil nutrients measured were extractable soil phosphorus, exchangeable soil potassium, magnesium and calcium.

Extractable P (ppm O. D. soil). Figure 15 represents the mean values of extractable soil P from the four sampling transects. There was a significant trend of increasing extractable soil P down the slope. The north slope had a higher mean value than the south slope (5.7 ppm

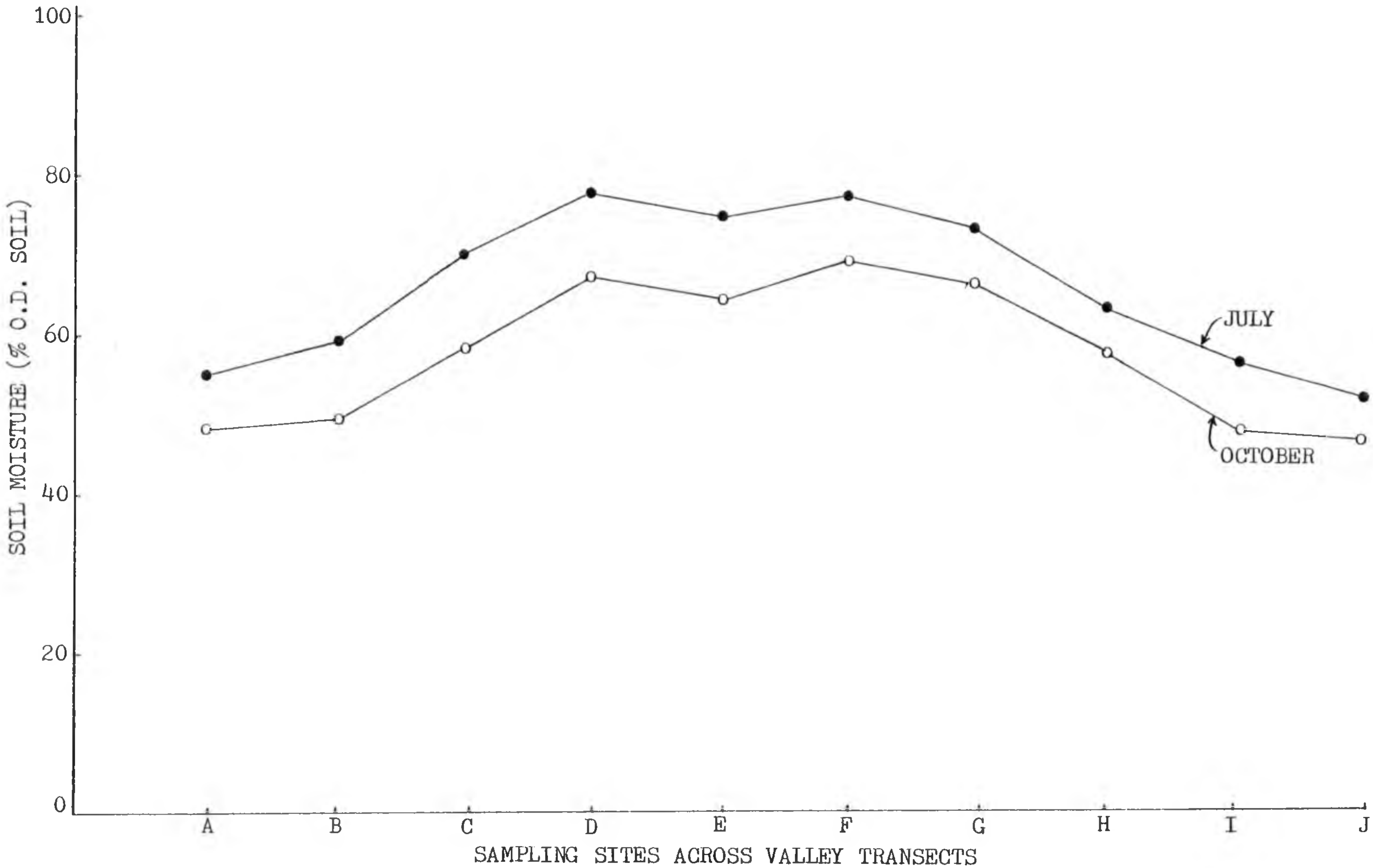


Figure 14: The gradient of soil moisture along the valley sampling transects in July and October. Site 'A' is at the top of the north slope and site 'J' at the top of south slope.

vs. 3.7 ppm). The mean extractable P was 4.7 ppm. This value is lower than that obtained by Nicholls (1972) with soil from the same area, because the area had not been fertilized since.

Exchangeable K (me/100g). There was no consistent trend of exchangeable K down the slope (Figure 15). The mean value for the pasture area was 0.26 me/100g, with a high of 0.39 me/100g and a low of 0.14 me/100g. These values are on the low side of the range 0.2 to 0.8 me/100grecorded for the soil of the same series.

Exchangeable Mg (me/100g). There was a significant increase in soil exchangeable Mg as one goes down the slope (Figure 15). The top of the slope had a mean value of 1.5 me/100g and the valley had a mean value three times higher (4.4 me/100g). The mean value for the pasture area was 3.3 me/100g.

Exchangeable Ca (me/100g). Figure 15 shows the mean trend of exchangeable Ca along the valley transects. The values were generally higher towards the bottom of the slope. Low values (less than 0.5 me/100g) were recorded at the tops of both slopes and the highest value was 2.4 me/100g recorded at position near the valley bottom. The mean value was 1.1 me/100g.

The higher values of exchangeable bases in the valley as compared to those at the tops of the slopes can be attribted to the soil profile of the valley. Nicholls (1972) found that the thickness of A-horizon increased going down the slope. The thickness of $A_2$ horizon increased from 12 cm at the top of the slope to 60 cm at location near the valley bottom. This soil was generally high in clay and organic matter and

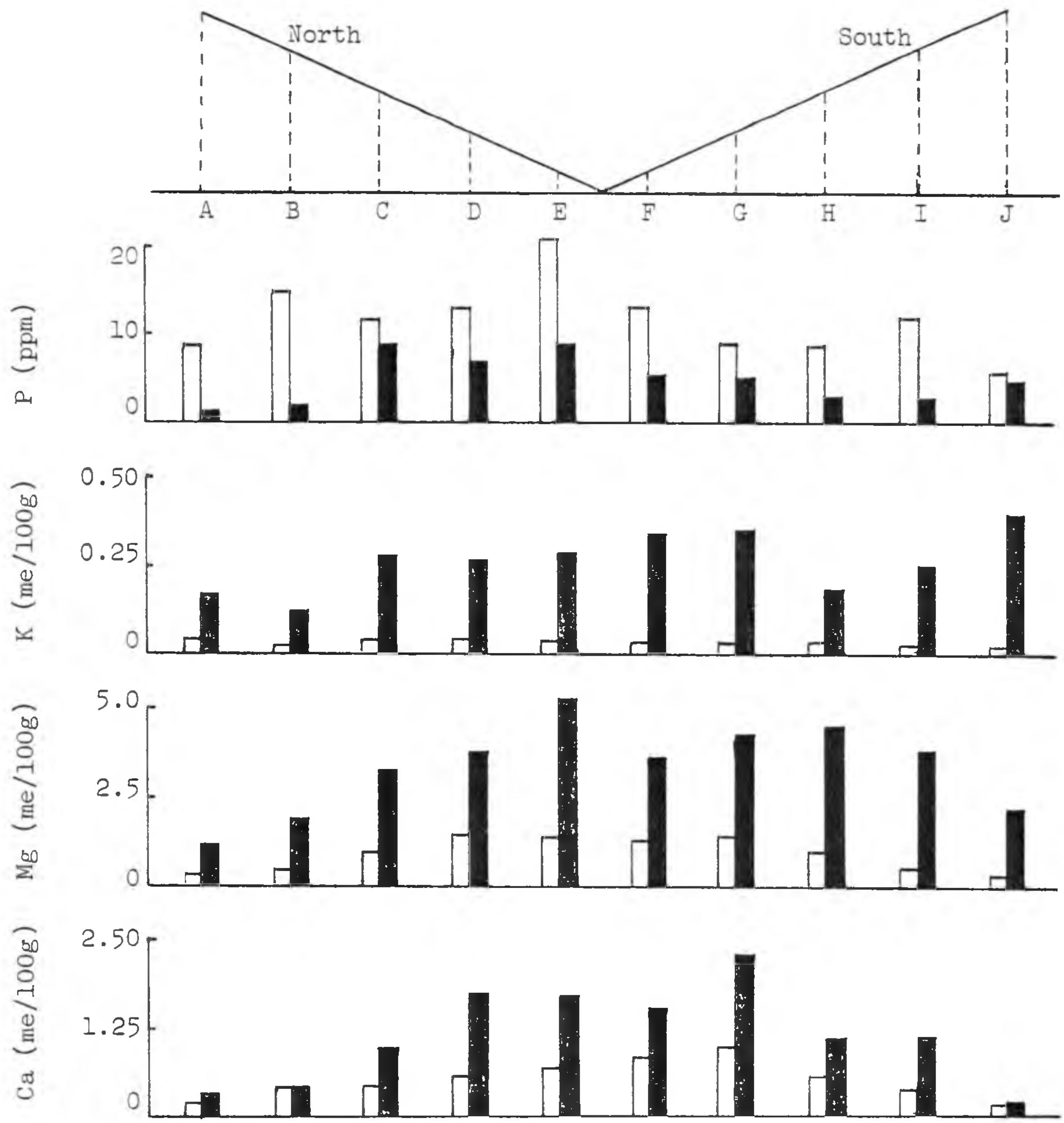


Figure 15. Extractable soil phosphorus and exchangeable soil potassium, magnesium and calcium along the north and south slopes in 1971 (unshaded) and in 1978 (shaded).

consequently high in exchangeable bases. The same trend was reported by Warren-Wilson and Leigh (1964).

Soil pH

The soil pH along the valley transects is shown in Figure 16. There was no significant trend going down the slope. The mean pH values for July and October were 6.2 and 4.6, respectively. It is not known why the values in July were higher than those of October. However, part of the increase might be due to slightly higher amounts of leached bases from the leaves of trees (Tamimi *et al.*, 1974), since June/July was wetter than September/early October.

Changes in Soil Moisture, pH and Nutrients Since 1971

In this comparison, results of Nicholls (1972) study were used to determine if any changes have occurred in soil moisture, pH, extractable soil P, exchangeable soil K, Mg and Ca.

Soil Moisture. Soil moisture increased down the slope. This was the trend in 1971 and was expected in 1978 for reasons discussed earlier.

Soil pH. Soil pH in 1971 showed a slight general decrease down the slope. But in 1978, there was no consistent trend. The mean pH value for the pasture area in 1971 was 4.9, and the mean values for July and October 1978 were 5.2 and 4.6, respectively. The pH values in July also showed a slight decrease going down the slope (same as in 1971). But in October the pH values were slightly higher at the valley bottom.

Soil Extractable P. Soil extractable P in 1971 at all locations on the pasture were in the range of 10 to 15 ppm, with higher values

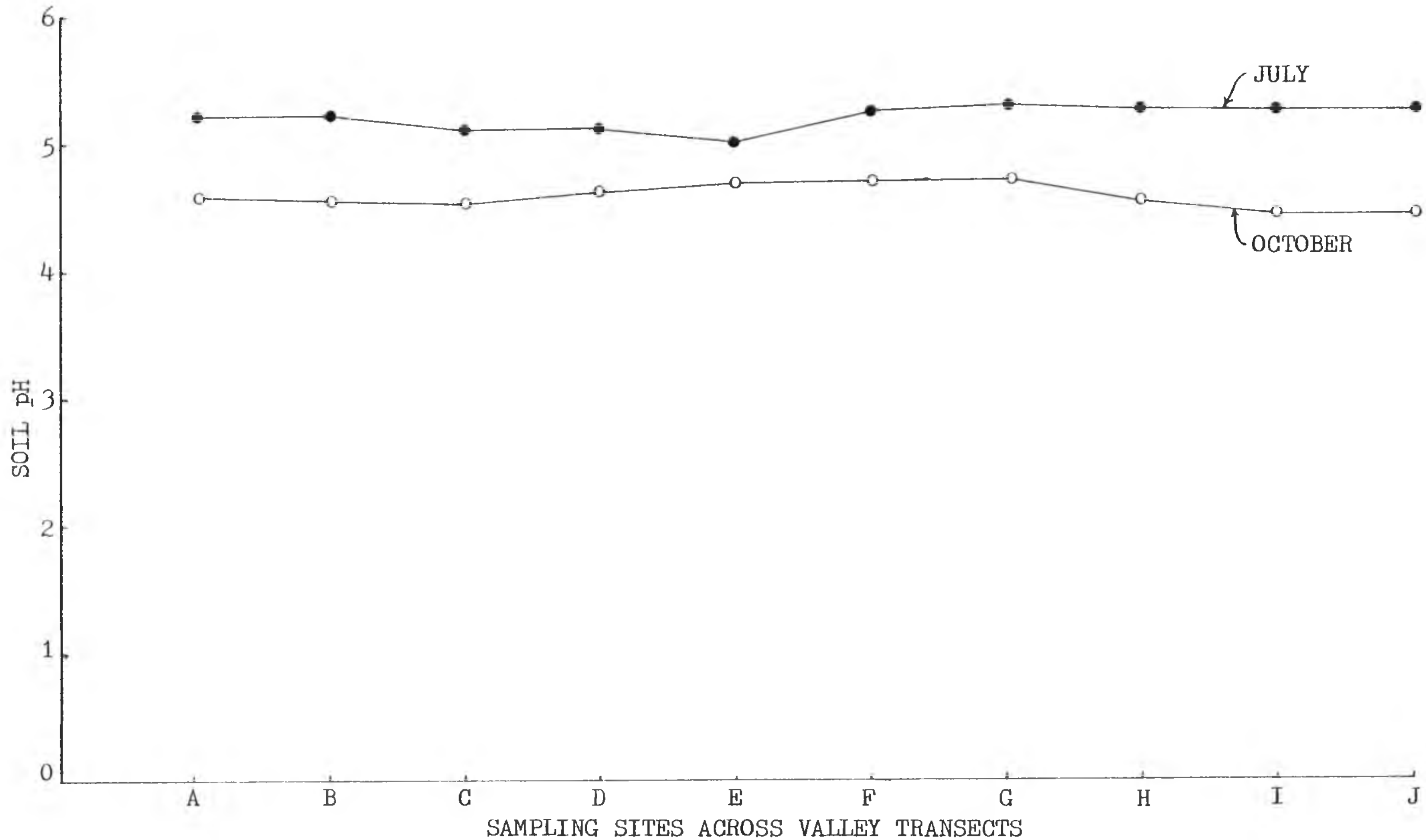


Figure 16: The gradient of soil pH of soil samples taken along the valley transects in July and October. Site 'A' is at the top of the north slope and 'J' at the top of south slope.

on the lower slopes (Figure 15). In 1978, extractable soil P had decreased. The decrease was more pronounced on top of the north slope, in which the P values dropped from about 12 ppm to 2 ppm (sites A and B). At the bottoms of both slopes, soil P decreased from 14 ppm to about 7 ppm.

The decrease in soil P in the pasture area over a period of seven years was expected because no P fertilizer had been applied to the area and the pasture was continuously grazed by cattle. The pronounced decrease in soil P on top of the slope could be due to 'transfer' of P in the form of cattle dropping from the top to the bottom of slope. This transfer may be of two ways: a) movement of cattle from the top to bottom of slope would spread dung to lower parts of the slope, and b) the dung deposited on top of the slope may be washed down the slope by rain. This effect appeared more pronounced on the steeper north slope.

Soil K. The mean soil K in 1978 was 0.26 me/100g. This value is in the range of 0.2 to 0.8 me/100g recorded for this soil series. The mean soil K in 1971 reported by Nicholls (1972) was considerably lower at 0.06 me/100g (Figure 15).

Soil Mg. There was no change in the trend of soil Mg of the pasture area after seven years, where exchangeable Mg increased going down the slope (Figure 15). The mean soil Mg in 1971 and 1978 were 1.4 and 3.3 me/100g, respectively. An increase in soil Mg was evident.

Soil Ca. The trend of exchangeable soil Ca in 1978 was similar to that obtained by Nicholls (1972). Soil Ca increased progressively down the slope. There was an increase in soil Ca over the seven year period

(Figure 15). The mean values of soil Ca in 1971 and 1978 were 0.6 me/100g and 1.1 me/100g, respectively.

It is not clearly known why increases in exchangeable soil bases were generally noted from 1971 to 1978 since the pasture was not fertilized. However, there was an increase in shrubby species (lantana, melastoma and guava). Their deeper root system may have extracted bases from lower soil depths. Leaching of nutrients, especially K, Ca and Mg, from the leaves of woody trees by rainwater (Tamm, 1951; Nye, 1961; Tamimi *et al.*, 1974) and subsequent decomposition from normal leaf fall may have deposited these bases in the surface zone of the soil where sampling was done.

# SUMMARY AND CONCLUSION

As the result of overgrazing and decline in soil fertility, a good pasture area would be dominated by weed species. In this study, the pasture species intortum had disappeared from the pasture. Green panicgrass was only found on steep areas and in lantana and melastoma thickets where it was protected from grazing. Stylo had spread to lower parts of both slopes and pangolagrass had increased and spread to the lower part of north slope.

Although some of the pasture species were present in the pasture, the dry matter on offer was very low because much of the area was covered by weeds. The four most common weed species in 1978 were elephantfoot, Boston fern, sour paspalum and glenwood grass. The shrubby weeds such as lantana, melastoma and guava had increased in number and size since 1971, thus reducing the 'open' area for spread of pasture species. Of the indicator weed species of 1971, all but American burnweed increased in number, indicating that these species were good indicators of pasture deterioration.

Of the soil factors measured, moisture and pH remained the same. Soil extractable P decreased and exchangeable K, Mg and Ca increased.

The effects of overgrazing and decline in soil phosphorus influenced the changes and increase in weeds in the pasture from 1971 to 1978, resulting in the pasture becoming unproductive.

# APPENDIX A

## EXTRACTABLE PHOSPHORUS

### Reagents and Standards

1. Extracting solution. 0.02N sulfuric acid [$H_2SO_4$] containing 3 g ammonium sulfate [$(NH_4)_2SO_4$] per liter.
2. Ammonium molybdate-sulfuric acid solution. Dissolve 25 g ammonium molybdate [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$] in 200 ml water in a beaker. It may be necessary to warm slightly to dissolve. Carefully add 275 ml concentrated sulfuric acid to about 400 ml water with mixing and cooling. Slowly, add the molybdate solution into the acid solution, mix and allow to cool. Dilute the combined solution to 1 l and store in the dark.
3. Stannous chloride solution. Dissolve 2.5 g of stannous chloride [$SnCl_2 \cdot 2H_2O$] in 10 ml of concentrated hydrochloric acid [HCl]. Dilute to 100 ml. Prepare immediately before use.
4. Standard P. Dissolve 0.2195 g of dry potassium dihydrogen phosphate crystals [$KH_2PO_4$] in water and dilute to 1 l. This solution contains 50 mg/l of P. Standards of 0, 2, 4, 6, 8 and 10 mg/l of P were prepared by diluting accordingly a known volume of stock solution with appropriate amount of water.

### Procedure

1. Place a 2 g sample of 20-mesh soil in a 500 ml Erlenmeyer flask. Add 200 ml of the extracting solution. Shake for 30 minutes and filter through Whatman's No. 40, refilter if turbid.
2. Pipette a 10 ml aliquot of filtrate into a 50 ml volumetric flask.

3. Pipette 10 ml aliquots of each standard into separate 50 ml volumetric flasks. For zero standard, use 10 ml of distilled water.

   From this point, treat standards and samples in the same way.

4. Add 2 ml of ammonium molybdate-sulfuric acid solution.
5. Dilute to volume with extracting solution. Add 3 drops of stannous chloride solution and mix. Allow about 30 minutes for the color to develop.
6. Pour a portion of the colored solution into a colorimeter tube and measure the optical density at 660 nm using water as reference.
7. Construct a calibration curve for the standards and use it to determine the concentration of P in the sample aliquots. Subtract blank value as necessary.

Calculation

$$\text{mg P per 100 g oven-dried soil} = \frac{C}{1000} \times 200 \times \frac{100}{2} \times MF$$

where, C = concentration of P in sample aliquot (mg/l).

MF = moisture factor.

EXCHANGEABLE CALCIUM, POTASSIUM AND MAGNESIUM USING ATOMIC ABSORPTION SPECTROSCOPE

Reagents and Standards

1. 1N ammonium acetate. Add 57 ml of glacial acetic acid into 800 ml of distilled water. Slowly, add 67 ml of concentrated ammonium hydroxide. Stir and adjust the pH to 7.0 by adding acetic acid or ammonium hydroxide. Dilute the solution to 1 l.

2. Lanthanum chloride solution (5000 mg/l La). Dissolve 6.6837 g of lanthanum chloride [$LaCl_3 \cdot 7H_2O$] in water. Add 1 ml of 2N HCl and dilute to 500 ml.

3. Sulfuric acid. 10%, v/v.

4. Calcium standard. Dissolve 2.4973 g of dry calcium carbonate [$CaCO_3$] in 200 ml of water containing 5 ml concentrated HCl. Boil the solution to drive off $CO_2$, cool, and dilute to 1 l with water. This solution contains 1000 mg/l Ca. Standards of 0, 1, 2, 5 and 10 mg/l were prepared by suitable dilution of original standard. Include sufficient lanthanum chloride solution to give a final La concentration of 800 mg/l. Add the 10% $H_2SO_4$ to each standard to give a final $H_2SO_4$ concentration of 1%. Also include ammonium acetate solution where necessary. For example, to prepare a standard of 1 mg/l of Ca, pipette 1 ml of original Ca standard into a 1 l volumetric flask. Add 160 ml of lanthanum chloride solution and 100 ml of sulfuric acid into the flask. Mix and dilute to volume with ammonium acetate solution.

5. Magnesium standard. Dissolve 1.0136 g magnesium sulfate [$MgSO_4 \cdot 7H_2O$] in water containing 1 ml concentrated $H_2SO_4$. Dilute to 1 l. This solution contains 100 mg/l Mg. Prepare standards of 0, 1, 2 and 3 mg/l of Mg by diluting the original solution. Include lanthanum chloride solution to give the final solution a concentration of 800 mg/l La. Add 10% sulfuric acid to each standard to give a final concentration of 1%. Also include ammonium acetate solution into the standards.

6. Potassium standard. Dissolve 1.9068 g KCl in water and make up to 1 l. This solution contains 1000 mg/l K. Prepare standards of 0 to 5 mg/l K by suitable dilution of the original solution. Include ammonium acetate solution in each standard.

Procedure

1. Place 25 g of 20-mesh soil into a 500 ml Erlenmeyer flask.
2. Add 200 ml of ammonium acetate solution. Let it stand for 24 hours with occasional shaking (or continuous shaking for one hour).
3. Filter the solution using Whatman's No. 5 filter paper. Wash with another 150 ml of ammonium acetate solution. Collect the filtrate for determination of calcium, potassium and magnesium using the atomic absorption method.

Procedure of Using Atomic Absorption Spectrophotometer

1. Switch on the instrument. Set the appropriate absorption wavelength. Adjust instrument settings, gas and airflow and lamp operating current as directed.
2. Adjust the scale reading to 100 with 1 mg/l standard after setting zero reading with distilled water.
3. Read off a range of standards to prepare a calibration curve.
4. Read off the readings using the samples. Check the stability of calibration from time to time using standards.
5. Flush with distilled water after reading each sample. Flush for at least a minute after reading a batch of samples.
6. Construct a calibration curve and read off sample concentrations and calculate concentration in original samples.

<u>Calculation</u>

If $C$ = concentration of element in sample (mg/l),

$MF$ = moisture factor,

$W$ = equivalent weight of the element,

mg of element per 100 g oven dried soil

$$= \frac{C}{1000} \times 350 \times \frac{100}{25} \times MF$$

m.e. of element per 100 g oven-dried soil

$$= \frac{C}{1000} \times 350 \times \frac{100}{25} \times \frac{MF}{W}$$

Appendix Table 1. Average monthly temperature and rainfall data of Kauai Branch Station from 1970 to 1978.

| Month | Rainfall (cm) | | Temperature (°C) | | | |
|---|---|---|---|---|---|---|
| | 1970-1977 | 1978 | 1970-1977 | | 1978 | |
| | | | max. | min. | max. | min. |
| January | 20.1 | 5.5 | 23.6 | 17.6 | 23.4 | 16.7 |
| February | 16.4 | 4.6 | 23.8 | 17.6 | 25.4 | 15.8 |
| March | 19.7 | 11.9 | 23.7 | 18.3 | 24.3 | 17.8 |
| April | 26.4 | 23.9 | 23.7 | 18.9 | 25.6 | 17.8 |
| May | 16.7 | 28.1 | 25.1 | 19.4 | - | - |
| June | 11.4 | 34.8 | 25.8 | 20.2 | - | - |
| July | 13.9 | 20.9 | 26.1 | 20.9 | 25.8 | 20.7 |
| August | 11.1 | 19.7 | 27.0 | 21.4 | 26.6 | 21.7 |
| September | 12.7 | 11.7 | 27.1 | 21.1 | 27.4 | 21.4 |
| October | 17.0 | 23.0 | 26.4 | 20.9 | 27.0 | 20.9 |
| November | 21.1 | 31.7 | 25.0 | 19.7 | 25.4 | 19.3 |
| December | 18.2 | 13.8 | 24.2 | 18.5 | 23.5 | 19.8 |
| Annual total | 204.7 | 229.6 | - | - | - | - |
| Annual mean | - | - | 25.1 | 19.5 | 25.5 | 19.2 |

Appendix Table 2. Correlation coefficients (r) of pasture and weed species.
df = 38, r = 0.31 (5%), and r = 0.405 (1%).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. *Digitaria decumbens* | | | | | | | | | | | | | | |
| 2. *Elephantopus mollis* | 0.04 | | | | | | | | | | | | | |
| 3. *Lantana camara* | -0.16 | 0.02 | | | | | | | | | | | | |
| 4. *Melastoma malabatricum* | -0.20 | -0.15 | 0.23 | | | | | | | | | | | |
| 5. *Nephrolepis exaltata* | -0.45 | -0.47 | -0.31 | 0.45 | | | | | | | | | | |
| 6. *Panicum maximum* | -0.36 | 0.25 | 0.50 | 0.40 | 0.19 | | | | | | | | | |
| 7. *Paspalum conjugatum* | -0.27 | 0.56 | -0.12 | -0.25 | 0.41 | -0.05 | | | | | | | | |
| 8. *Paspalum orbiculare* | -0.10 | -0.33 | 0.25 | 0.51 | 0.32 | 0.28 | -0.48 | | | | | | | |
| 9. *Psidium guajava* | -0.51 | 0.21 | -0.36 | -0.32 | -0.13 | -0.25 | 0.35 | -0.52 | | | | | | |
| 10. *Sacciolepis indica* | 0.07 | 0.38 | -0.23 | -0.19 | -0.33 | -0.17 | 0.66 | -0.32 | 0.20 | | | | | |
| 11. *Setaria geniculata* | 0.01 | 0.33 | 0.38 | 0.21 | -0.21 | 0.56 | 0.16 | 0.39 | -0.41 | -0.05 | | | | |
| 12. *Stylosanthes guianensis* | 0.47 | -0.17 | 0.22 | 0.39 | 0.03 | 0.40 | -0.37 | 0.68 | -0.62 | -0.32 | 0.51 | | | |
| 13. *Stachytarpheta urticaefolia* | -0.21 | 0.40 | 0.11 | -0.10 | -0.27 | 0.50 | 0.04 | 0.13 | 0.05 | -0.14 | 0.57 | 0.31 | | |
| 14. Lantana/guava/melastoma | -0.68 | 0.09 | - | - | 0.39 | 0.50 | 0.29 | 0.12 | - | -0.15 | 0.11 | -0.08 | 0.03 | |

Appendix Table 3. The trend in the distribution of species and soil factors along the transects using BLSD. Site A is at the top of north slope and J is at the top of south slope.

| Site | *Digitaria decumbens* | *Elephantopus mollis* | *Lantana camara* | *Melastoma malabathricum* | *Nephrolepis exaltata* | *Panicum maximum* | *Paspalum conjugatum* | *Paspalum orbiculare* | *Psidium guajava* | *Sacciolepis indica* | *Setaria geniculata* | *Stachytarpheta urticaefolia* | *Stylosanthes guianensis* | *P. conjugatum*/ *S. geniculata* | Soil Moisture | Soil pH | Soil P | Soil Ca | Soil K | Soil Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | c | a | a | ab | – | a | – | bcd | ab | a | ab | a | cd | ab | ab | – | a | a | – | a |
| B | b | a | abc | bc | – | abc | – | d | ab | ab | ab | a | cd | ab | abc | – | a | a | – | a |
| C | ab | a | d | abc | – | cd | – | cd | b | abc | bc | abc | cd | abc | cde | – | d | b | – | bc |
| D | a | ab | cd | ab | – | cd | – | ab | c | abc | b | bcd | a | abc | e | – | d | de | – | cd |
| E | a | abc | ab | a | – | ab | – | a | d | abcd | a | ab | a | a | de | – | d | cde | – | e |
| F | – | c | ab | ab | – | abc | – | ab | cd | abcd | ab | cd | ab | ab | e | – | c | bcd | – | cd |
| G | – | c | bcd | ab | – | cd | – | abc | b | bcd | d | de | bc | d | de | – | bc | e | – | cde |
| H | – | bc | abc | abc | – | d | – | bcd | ab | cd | d | cd | cd | d | bcd | – | abc | bc | – | de |
| I | – | ab | bcd | c | – | cd | – | cd | a | cd | cd | e | d | bc | ab | – | ab | bc | – | cd |
| J | – | a | cd | abc | – | bcd | – | cd | ab | d | cd | bcd | cd | cd | a | – | bc | a | – | ab |
| Site sig. | ** | ** | ** | ** | NS | ** | NS | ** | ** | * | ** | ** | ** | ** | ** | NS | ** | ** | NS | ** |
| Trans. sig. | ** | * | NS | NS | NS | NS | NS | NS | NS | ** | NS | ** | ** | * | ** | NS | NS | ** | NS | ** |

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